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Report No. CG-D-3-87

TARGETS OF OPPORTUNITY EXPERIMENT: SHORT RANGE AIDS/RADIO AIDS PRINCIPAL FINDINGS: WATERWAY PERFORMANCE, DESIGN AND EVALUATION STUDY

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16. Abstract

This report describes one of a series of man-in-the-loop simulation studies designed to assist the USCG in the design and evaluation of systems of aids to navigation. Previous studies have examined various configurations of buoys in the absence of any other visible objects. The present study was undertaken to determine the extent to which representative visual surroundings would augment the effectiveness of a system of aids. In addition to comparing performance in the presence of a typical visual scene to performance in the absence of other objects, particular features of the visual environment were varied in order to better define the means by which the visual scene affords improved performance. The results indicated that aids to navigation are in fact more effective in typical visual surroundings than they are with no other objects in the scene. It was found that the amount of benefit associated with the visual scene was influenced by a variety of factors including the density of objects in the scene and the distance of objects from the waterway. However, the presence of a visual environment was generally not found to improve performance for a suboptimal buoy configuration to that of an optimal configuration. The implications of the experiment for waterway design are discussed, and guidelines for the evaluation of visual environments are presented.

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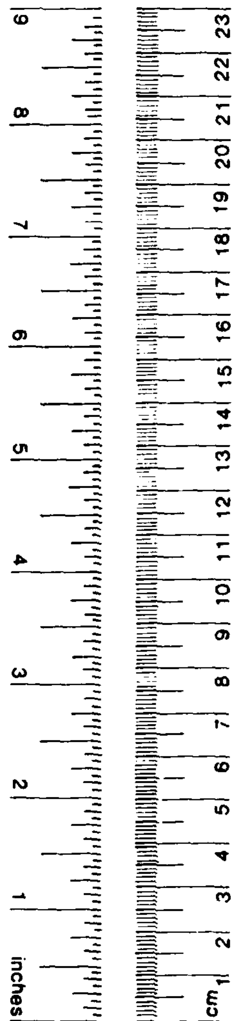
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

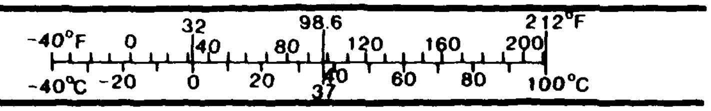
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures. Price $2.25. SD Catalog No. C13.10 286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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We would like to thank Mr. Harry J. Crooks, Director of the Safety and Education Plan of District 2 of the Marine Engineers Beneficial Association - Associated Maritime Officers - AFL-CIO, and his staff there.

We are also indebted to CAPT Daniel Coleman, president of the Lakes pilot Association and the members of that association who provided shiphandling expertise for the experiment.

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EXECUTIVE SUMMARY

THE WATERWAY PERFORMANCE, DESIGN, AND EVALUATION PROBLEM

The United States Coast Guard's Aids to Navigation Manual-Administration states that "Aids to navigation only supplement natural and man-made landmarks and those other environmental features which provide the mariner with cues needed to navigate. Consequently, existing geographic composition must be considered throughout the design process." On the other hand, the Short Range Aids to Navigation Systems Design Manual for Restricted Waterways was based on simulator performance data collected for aids alone, without landmarks or other features. Therefore, those performance data, expressed as relative risk factor (RRF) values in the Systems Design Manual, Section 5, are conservative in that they may over-estimate risk for waterways in view of land. The design guidelines of Section 4 are also conservative in that they may recommend more aids than may be necessary in some circumstances.

THE TARGETS OF OPPORTUNITY EXPERIMENT

The objective of the present experiment was to examine the possibility that low densities of aids might be appropriate for narrow, buoyed channels with nearby landmass and landmarks. The experiment was designed to measure the degree to which the performance of a low-density arrangement, backed by land, would approximate that of a higher-density arrangement, not backed by land.

- An aid arrangement with a relatively high density of buoys, found during the earlier Phase of the Study to be a high performer, was replicated to provide a standard to which to compare other conditions. This arrangement has a three-buoy turn and gated buoys in the straightaway.
- Also replicated was a lower-density, lower-performing arrangement. The second arrangement has one turn buoy and staggered buoys in the straightaway.
- The lower-density arrangement was run with a variety of landmasses surrounding it. The landmasses differed in the density of objects on the shore, in the relative bearing of the landmass from the ship at the turn maneuver, in distance from the channel edge, and in day/night conditions. For the sake of generality of findings, no specific objects were designated as landmarks or targets of opportunity (TOOs).

THE MARITIME TRAINING AND RESEARCH CENTER

The present experiment was done at the Maritime Training and Research Center (MTRC) in Toledo, Ohio. This simulator was developed by Ship Analytics for the Marine Engineer's Benevolent Association, District 2, and is operated jointly by the union and the company.

The MTRC simulator is based on the USCG/SA prototype simulator on which the earlier experiments were done. It is more elaborate and more advanced than the earlier simulator. For present purposes, it has a rear screen; the capability of a more complex visual scene, including landmasses and cultural objects; and more sophisticated and realistic ship hydrodynamic models.

THE EXPERIMENTAL METHODOLOGY

The general methodology used in the earlier experiments has been retained. The waterway characteristics and shiphandling task were kept constant across scenarios; while the piloting conditions, here aid arrangements and landmass, were changed. The waterway and shiphandling tasks were as similar as possible to the earlier experiments to facilitate comparisons. The MTRC 30,000 dwt tanker model was more realistic than the model used earlier; and it was modeled in a fully loaded, rather than ballasted, condition, a difference that is more conservative for experimental purposes.

Eight pilots, licensed as U.S. Registered Pilots by the U.S. Coast Guard, transited each of nine scenarios. The primary performance data were based on the mean and standard deviation of the crosstrack distribution of their transits through the channel. Differences in piloting information provided by aids and landmass should be reflected in the precision of the tracks.

EXPERIMENTAL RESULTS

- The higher-density aid arrangement supported the best performance in the experiment. The lower-density aid arrangement without landmass resulted in the poorest performance in the experiment. This finding replicates that of earlier experiments on which the Disian Manual is based.

- The conditions of lower-density aid arrangement backed by variations in landmass arrayed themselves between the extremes of the two aids-only arrangements. No combination of lower-density of aids and landmass reached the level of performance of the higher density of aids alone.

- Favorable variations in landmass -- a higher density of the cultural objects, daytime, etc. -- generally had their greatest favorable effects in the turn pullout region. The effects were less in the recovery region and minimal in the trackkeeping region. Apparently, pilots made more use of the additional information provided by the landmass for the more difficult maneuvers.

- Points of land close the channel edge resulted in very good performance for the single maneuvering region closest to them. This finding is generalized to apply to a variety of conspicuous, salient objects close to the channel edge, including USCG - provided fixed structures.

INTERIM GUIDELINES FOR EVALUATING THE CONTRIBUTION OF LANDMASS

The overall plan for the Waterway Study is to use the findings of the TASK 1 simulator experiments for a revision of the Design Manual under TASK 6 in 1989. This report provides interim guidelines to be used until then in the evaluation of the contribution of nearby landmass to waterway performance. It recommends the following additions or modifications to the Manual's design and evaluation process:

1. It is recommended that the designer examine the waterway for discrete, conspicuous landmarks close to the channel edge. These landmarks -- or fixed structures -- may justify changes in RRF for the better in nearby regions.

2. It provides a methodology for an evaluation of the contribution of nearby landmass to piloting with a low-density aid arrangement. The evaluation has both quantitative and qualitative components. RRF values calculated from Manual data for high- and low-density aid arrangements provide a quantitative range within which performance would fall. Instructions are provided for a qualitative interpolation within this range, based on the features of the landmass surrounding the waterway.

3. Special recommendations are provided for nighttime transits. Nighttime transits with a low-density aid arrangement and nearby land-based lights can be considered the equivalent of daytime Manual data without land and the lower (better) RRF values used.

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Section 1

INTRODUCTION

1.1 THE TARGETS OF OPPORTUNITY (TOOs) EXPERIMENT

The United States Coast Guard's Aids to Navigation Manual-Administration[1] states that "Aids to Navigation only supplement natural and man-made landmarks and those other environmental features which provide the mariner with cues needed to navigate. Consequently, existing geographic composition must be considered throughout the design process." On the other hand, the Short Range Aids to Navigation Systems Design Manual for Restricted Waterways[2] was based on simulator performance data collected for aids alone, without landmarks or other features. Therefore, those performance data, expressed as relative risk factor (RRF) values in the Systems Design Manual, Section 5, are conservative in that they may overestimate risk for waterways in view of land. The design guidelines of Section 4 are also conservative in that they may recommend more aids than are necessary in some circumstances.

The conservatism of the Systems Design Manual was illustrated during the PHASE II Addendum of the research study. During the VALIDATION task, a comparison was made of at-sea and simulator performance data for the approach to Providence, Rhode Island. Simulator performance generally provided a good match to at-sea data. The only substantial difference between simulator and at-sea performance appeared in Conimicut Reach at night. This is a reach that is only sparsely marked by aids, but at sea is close to land. In the VALIDATION report, it was hypothesized that the aids-only simulation did not fairly represent conditions when at-sea performance was dependent on the contribution of nearby land.[3]

The Targets of Opportunity (TOOs) experiment provides information on the contribution of nearby landmass and landmarks to guide the design of an efficient aid system for a waterway. During the planning of the experiment, it was decided to define "Targets of Opportunity" (TOOs) very broadly as nearby landmass with a variety of natural and man-made objects available to the pilots. The pilots were not instructed in the selection or use of any specific objects. Such a definition of TOOs means the resulting performance data has generality: that is, it can be applied to a wide variety of waterways with variously effective TOOs. It also means the resulting performance data are conservative: that is, it may overestimate risk and lead to cautious design for some waterways with very effective TOOs but will not lead to unsafe design where TOOs are not effective.

[1] United States Coast Guard, Aids to Navigation Manual-Administration, COMMANDANT INSTRUCTION M16500.7. U.S. Coast Guard, Washington, D.C. 20593.

[2] Smith, M.W., K.L. Marino, and J. Multer Short Range Aids to Navigation Systems Design Manual for Restricted Waterways, (CG-D-18-85, United States Coast Guard, Washington, D.C. 20593 (NTIS AD-A158213).

[3] Smith, M.W., K.L. Marino, J. Multer, and J.D. Moynehan Aids to Navigation Principal Findings Report: Validation for a Simulator-Based Design Project CG-D-06-84, United States Coast Guard, Washington, D.C. 20593 (NTIS AD-A146789).

1.2 THE WATERWAY PERFORMANCE, DESIGN AND EVALUATION STUDY

The Waterway Performance, Design and Evaluation Study is the third phase of a United States Coast Guard Study. The earlier phases of the study were the Aids to Navigation Systems, Design and Evaluation Study, Phases I and II.

The central principles, on which the Study is based, were established during PHASE I. Among these is the understanding that an analytical tool must be based on an empirical analysis of the navigation process. Also established during PHASE I was the feasibility of collecting performance data in a controlled manner for a given set of conditions, at sea or on the simulator.

PHASE II (1979-1982) was the major effort. The methodology of investigating component aspects of the problem and collecting data was developed. The United States Coast Guard/Ship Analytics prototype simulator was designed and built to support data collection. The experiments -- conducted both at CAORF, the Maritime Administration's Computer Aided Operations Research Facility; and on the prototype simulator -- were a broad exploration of all important variables. A draft design manual was written to provide an exploration of the possibilities of a manual format. It was during the writing of the draft manual that the relative risk factor (RRF) was selected as the principal index for quantifying the performance of an aid system. It is an inclusive index that considers the empirical crosstrack mean and standard deviation of a set of transits, the ship size, the ship's aspect in the channel, and the channel width. The RRF is a relative assessment of the risk, or probability, that there will be a grounding under the tested condition.

The PHASE II ADDENDUM developed and refined some of the innovations of the earlier phases. The simulator experiments -- done, again, at CAORF and on the USCG/SA simulator -- were special purpose rather than broad. The aid systems study's recommendations were supported by a validation of the USCG/SA simulator and a trial implementation of the draft manual. The current Design Manual[4] was written, benefiting from the later work and from experience with the draft manual. The Design Manual contains a review of the earlier work.

This phase will continue the development and refinement of earlier work and will extend into new areas. The planned experiments are largely special purpose. This report describes the first of these. A new tool for the evaluation of the risk contributed by Ship Performance will be developed. The major objective of the new work is the Revision of the Design Manual.

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[4] op. cit.

1.3 THE MARITIME TRAINING AND RESEARCH CENTER (MTRC)

The TOOs experiment was performed at the Shiphandling Simulator Facility located at the Maritime Training and Research Center (MTRC) in Toledo, Ohio. This facility was designed and built by Ship Analytics Inc., for the Marine Engineer's Benevolent Association (MEBA) and is operated jointly by the union and the company. The simulator was designed with a full spectrum of capabilities to support both operational training and research, and with the flexibility and expandability to support a variety of future requirements. Its capability to simulate the marine environment for the mariner has been proven by the successful development and implementation of a variety of training and research programs. Its capability to simulate the marine environment for the mariner has also been uniquely proven by the validation of the simulator developed for the United States Coast Guard's Aids to Navigation Systems, Design and Evaluation Study, PHASE II[5]; since the same techniques are used at MTRC for scene generation, hydrodynamics, data collection, and a variety of other functions. The simulator is described in Appendix A.

[5] op. cit.

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Section 2
THE DESIGN OF THE EXPERIMENT

2.1 OVERVIEW OF THE DESIGN

The findings of the experiment described here will provide guidance for the district system designer in evaluating the support provided by the visual shoreline environment containing natural and cultural objects: that is, targets of opportunity (TOOs). He will then be better able to design an aid system that will "supplement" that visual environment. The logic of the anticipated design process is illustrated by Figure 1. The "preferred aid arrangement" is one that was demonstrated in earlier experimentation to support the needs of the piloting process, without any other visible objects.

Performance using that arrangement can be used as a standard to which to compare other arrangements. An arrangement using fewer aids, with lower associated cost, was demonstrated in earlier experimentation to result in poorer piloting performance, without other visible objects. However, the lower density (aids per nautical mile) aid arrangement may approximate the performance of the preferred arrangement in some situations. The experiment is designed to discover the important variables determining those situations.

In the experiment, aids-only scenarios were compared to aids backed by a variety of visual environments, containing TOOs. The variables the experiment was designed to evaluate are as follows:

- aid arrangement: preferred (three-buoy turn, gated) versus low density (one-buoy turn, staggered)
- aid environment: aids-only versus aids plus representative visual environment
- density (number per nautical mile, nm) of TOOs: low, moderate, high
- relative bearing of TOOs from turn: all around, abeam at setup, abeam at pullout
- distance of TOOs from turn: 1.5 nm versus 2.5 nm
- time of day: day/night

2.2 AID ARRANGEMENTS AND A REPRESENTATIVE VISUAL ENVIRONMENT

2.2.1 Evaluation of Aid Arrangements

A high density buoy arrangement (three turn buoys/gated buoys at 1.25 nm intervals) was shown in Phase II experiments to consistently support the best piloting performance. From the consistently better performance, it was inferred that the arrangement supported the pilot's information needs, without the need for additional channel marking or other sources of information. It has been recommended as a preferred aid arrangement for minimal risk. A low density arrangement (one turn buoy/staggered buoys at 1.25 nm intervals along a single side) was associated with consistently poorer performance in Phase II. From the consistently poorer performance it

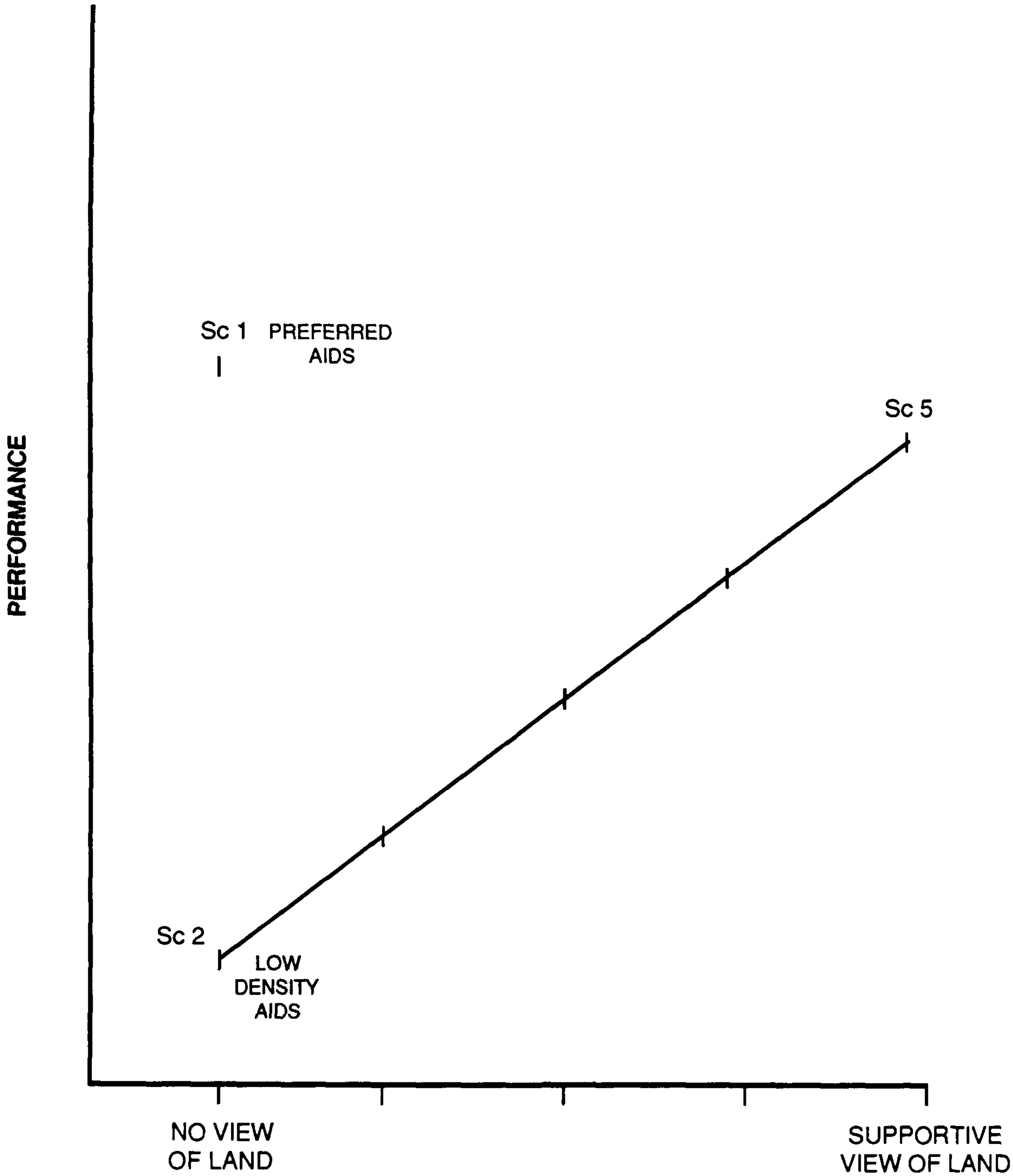

Figure 1. The Logic of the Design Process

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was inferred to represent a situation in which the channel marking per se does not supply the pilot with sufficient information when other information is not available. It has generally not been recommended.

These two aids-only conditions are represented in this experiment by Scenarios 1 and 2. The conditions are summarized in Table 1. The arrangements are illustrated by chartlets in Appendix B. Performance in each of the aids-only conditions served as a standard against which performance associated with the other conditions was measured. For example, the contribution to the piloting process of a particular visual environment was indicated by the extent to which performance in the presence of that environment was superior to performance in the low density, aids-only condition. The adequacy of information provided by visual environment was indicated by how closely the performance in the visual environment approached that associated with the high-density buoy condition. See Figure 1.

Performance in these scenarios was also compared to data collected in Phase II under similar conditions. These comparisons are described in Section 6.

2.2.2 A Representative Visual Environment

As suggested in the Introduction, the present experiment was intended to investigate the possibility that aids-only simulation was responsible for the poor performance of the low density arrangement of aids evaluated in previous experiments. Since many marked waterways are within sight of land, the usefulness of the low density arrangement in actual waterways may have been underestimated. Accordingly, the present study examined piloting performance with a low density buoy arrangement in the presence of a visual environment that was representative of a typical real-world shoreline adjacent to a waterway. The one visual environment that was selected as "representative" and used most frequently in this report was Scenario 4, summarized in Table 1. It had the low density aid arrangement, a moderate density of cultural objects, a landmass all around the channel, a shoreline within 1.5 nm of the channel edge, and was run under daytime conditions. A chartlet illustrating the configuration of aids and land appears in Appendix B.

2.3 VARIATIONS IN THE VISUAL ENVIRONMENT

The performance data from this experiment will be used to provide an evaluation of the contribution of the surrounding view of land. A variety of visual environments were evaluated with the low density buoy arrangement. The combination of variations in the visual environment with a low density of buoys served the experimental purpose of increasing the pilots' dependence on the visual environment and revealing differences in the usefulness of each variation. The variations in visual environment that were evaluated are summarized in Table 1. They vary from the representative visual environment in Scenario 4 in density of objects, relative bearing of land and objects from the turn, distance of the shoreline, and in day/night conditions. The variations are illustrated in Appendix B.

TABLE 1. EXPERIMENTAL SCENARIOS

Scenario	Aids	Targets of Opportunity (TOOs) in Visual Surround: Density	Relative Bearing	Distance	Day/Night
Objective: Familiarization					
FAM	3-buoy turn, gated buoys	high, cultural objects	all around	within 1.5 nm*	day
Objective: Evaluation of Aid Arrangements					
1	3-buoy turn, gated buoys	none	none	none	day
2	1-buoy turn, staggered buoys	none	none	none	day
Objective: Evaluation of the Visual Environment: Density of Objects					
3	1-buoy turn, staggered buoys	low, landmass	all around	within 1.5 nm	day
A Representative Visual Environment					
4	1-buoy turn, staggered buoys	moderate, cultural objects	all around	within 1.5 nm	day
5	1-buoy turn, staggered buoys	high, cultural objects	all around	within 1.5 nm	day
Objective: Evaluation of Visual Environment: Relative Bearing of Objects					
6	1-buoy turn, staggered buoys	moderate, cultural objects	ahead setup, abeam pullout	within 1.5 nm	day
7	1-buoy turn staggered buoys	moderate, cultural objects	abeam setup, aft pullout	within 1.5 nm	day
Objective: Evaluation of Visual Environment: Distance					
8	1-buoy turn, staggered buoys	moderate, cultural objects	all around	within 2.5 nm	day
Objective: Evaluation of Visual Environment: Day/Night					
9	1-buoy turn, staggered buoys	moderate, cultural lights	all around	within 1.5 nm	night

*nm is nautical mile

Section 3

SIMULATION METHODOLOGY

3.1 SIMULATED WATERWAY, WIND AND CURRENT

The basic channel configuration was the same throughout the experiment (see Figure 2). It consisted of two legs connected by a 35-degree turn to port. In Leg 1 there was a following current which diminished in magnitude from 1.2 knots at the start of the transit to approximately 0.9 knots at the turn pullout. In Leg 2, the current was on the vessel's port quarter and continued to decrease in magnitude, reaching zero knots by the end of the transit. Throughout the transit, the wind was from 166 degrees at a speed of 30 knots.

3.2 SHIPHANDLING TASK

The general approach for the simulator data collection is to design a shiphandling task and to keep it constant across scenarios while the piloting variables -- aid arrangement and visual environment -- change. The shiphandling task has been carried over from the experiments of Phase II, to facilitate the comparison of performance data across phases.

The scenario events and the performance requirements are illustrated in Figure 2. This figure is taken from the "Instructions to Pilot" in Appendix B. It is accompanied there by a discussion for the pilot's use.

The shiphandling tasks are designed to be somewhat more difficult than would be strictly realistic in order to increase the pilot's dependence on the aids and the visual environment, and to increase the likelihood of finding differences in ship tracks between scenarios/experimental conditions. In Leg 1 with a following wind and current, the slow 6-knot speed and the instructions to maintain a strict centerline track have not often revealed meaningful differences among scenarios. In Leg 2, cross wind and current require a crab angle (of as much as 4 degrees near the turn) to maintain the centerline at that slow speed. There, the shiphandling task generally has revealed differences among conditions in the second leg.

3.3 SHIP MODEL

The ship hydrodynamic model used was a 30,000 deadweight ton (dwt) tanker available at MTRC. It is 595 feet long between perpendiculars, 85 feet in beam, with a draft of 34.6 feet. It is modeled fully loaded. It has a split house with the eye location in the bridge 85 feet forward of the center of gravity and 47.5 feet above the water. The engine order telegraph-to-speed table and turning circles appear in the instructions to the pilot.

3.4 PARTICIPANTS

The eight test subjects used in this experiment are licensed as U.S. Registered Pilots by the U.S. Coast Guard. All of the test subjects also have attained the following licenses or endorsements:

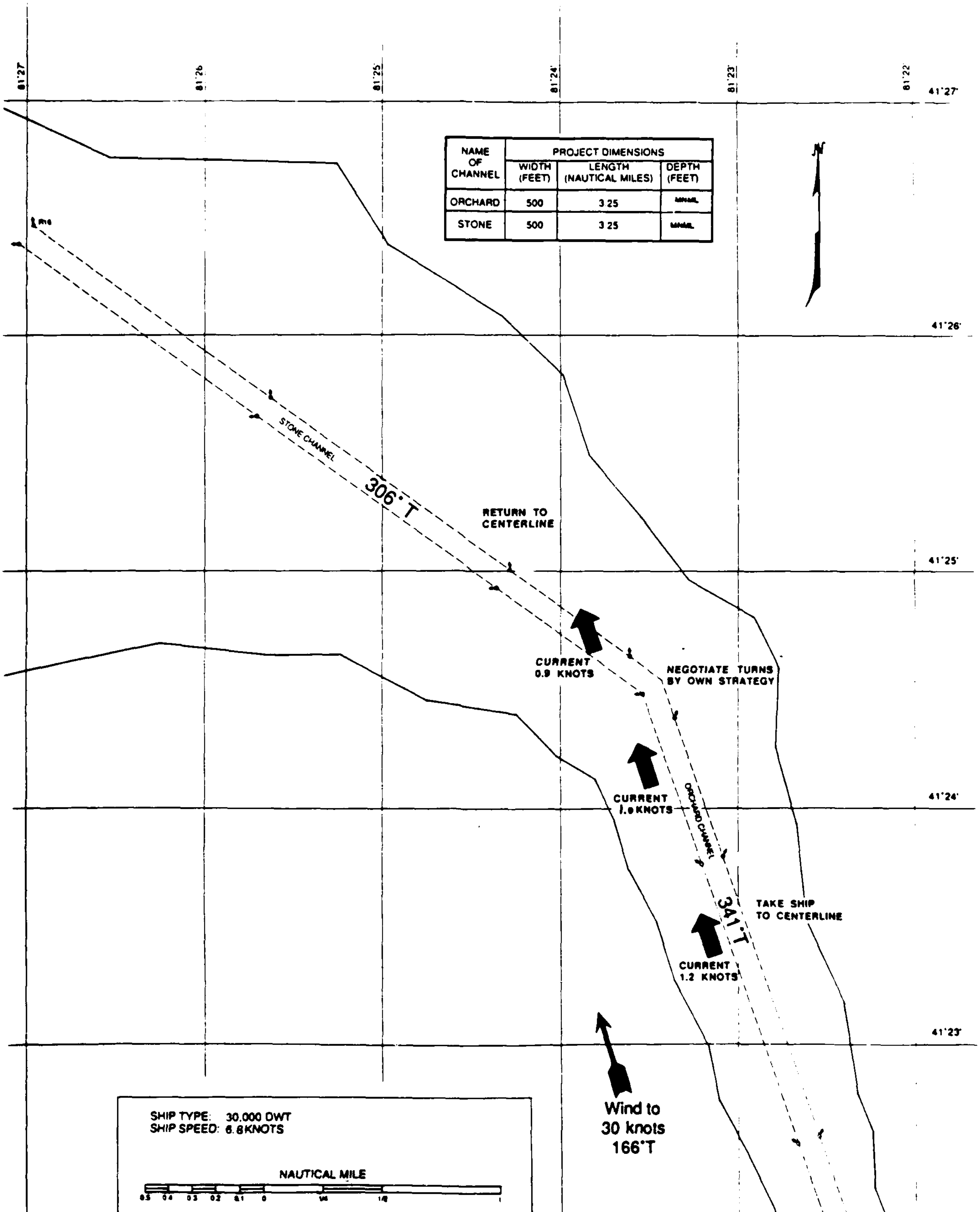

Figure 2. Simulated Waterway, Wind and Current

- First Class Pilot's license for Duluth, Gary, Buffalo, and all rivers
- U.S. Coast Guard Certified Radar Observer

The pilots participating in this experiment actively pilot ocean-going vessels, as large as 30,000 dwt and 600 feet in length, entering the Great Lakes. Each of the pilots had recent experience piloting ships through restricted waterways that are comparable to those simulated in the experiment.

One pilot with previous experience at the MTRC simulator came in for consultation and was run through the experimental procedure. As a result of this day, changes were made to the experimental conditions and his data was not included in the analysis.

3.5 PROCEDURES

3.5.1 Daily Agenda

Each pilot's day consisted of the following events.

1. The briefing was based on the "Instructions to the Pilot" which appears as Appendix B.

2. The familiarization run was meant to familiarize the pilot with the channel, wind, current, and ship. It was run with maximum piloting information: day, three - buoy turn, gated buoys, land all around, and high density of objects. It included an additional maneuver not included in the experimental scenarios to increase the pilot's familiarity with the maneuvering performance of the ship: an approach and turn on to the channel. It is illustrated in Appendix B.

3. The experimental scenarios were run in random order (as described below) for each subject. Their content appears in Appendix B.

4. Subjective data were collected from the pilots using the questionnaire attached as Appendix C. The discussions guided by the questionnaire were conducted throughout the day as opportunity and issues presented themselves.

3.5.2 Run Order

The run order for each pilot is presented in Table 2. It was produced by randomizing the run order for Subject 1 and then counting down the columns. The random order for each subject assures that there will be no carry-over effects (one scenario repeatedly influenced by the preceding scenario). The counterbalancing over columns ensures that no scenario was biased by appearing consistently at any position in the order (early in the day when the pilot was less familiar with the channel and ship, or late in the day when he might have been tired or bored).

TABLE 2. ORDER OF SCENARIOS FOR SUBJECTS

SUBJECT	1	2	3	4	5	6	7	8	9	10
1	FAM	1	7	6	9	5	8	4	2	3
2	FAM	2	8	7	1	6	9	5	3	4
3	FAM	3	9	8	2	7	1	6	4	5
4	FAM	4	1	9	3	8	2	7	5	6
5	FAM	5	2	1	4	9	3	8	6	7
6	FAM	6	3	2	5	1	4	9	7	8
7	FAM	7	4	3	6	2	5	1	8	9
8	FAM	8	5	4	7	3	6	2	9	1

Section 4

SIMULATOR DATA COLLECTION AND PERFORMANCE MEASURES

4.1 SIMULATOR DATA COLLECTION

During the simulation a variety of data were recorded for potential later examination and analysis. They were as follows.

1. Computer-Recorded Measures. As the "ship" transited the channel, its crosstrack position was recorded as a function of along track position. These measures formed the primary data of the experiment. Their use is described in the following subsections. The computer also recorded other ship status measures, including: speed, yaw rate, heading, course, rudder angle, and engine revolutions per minute.

2. Operator-Entered Measures. The pilot's helm orders -- course, rudder, and engine order telegraph -- were entered at the terminal by the simulator operator. These orders were recorded by the computer along with measures of ship's position and status.

3. Pilot's Subjective Reactions. The pilot's comments and reactions to all aspects of the simulation were noted by the researcher. The questionnaire that was used to guide the discussion appears as Appendix C.

4.2 SUMMARY OF SCENARIO PERFORMANCE

After the simulation phase of the experiment, the ship position measures were accessed and subjected offline to a number of calculations and plots. A sample of a "combined" plot appears on page D-3. First, at "data lines" placed at 475-foot intervals along a channel, the performance for the eight transits of each scenario is summarized by calculating the mean and standard deviation of the crosstrack position of ownship's center of gravity. The placement of the data lines is illustrated on page D-3 by the tick marks along the channel edge. The performance in a scenario can be described by plotting the crosstrack mean and standard deviation as a function of along track distance, or data line. Such plots are illustrated by the top two axes on page D-3. The mean and standard deviation can be combined to provide a graphic envelope of expected performance within the channel boundaries. The "envelope" on the third axis of page D-3 is formed by the mean with two standard deviations to either side. The envelope represents 95 percent of expected transits for the tested conditions.

4.3 COMPARISONS BETWEEN SCENARIO CONDITIONS

A "comparison" plot is illustrated on page E-3. The means and standard deviations from two different scenarios are plotted on the same axis. Such comparisons are made more meaningful with statistical tests. The means were compared using a t-test; the standard deviations were compared as variances, using an F-test. These are both frequently used tests. One description of them appears in McNemar.[6] In comparison plots the arrows along the abscissa indicate statistically significant differences at the 0.10 level at the corresponding data lines.

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[6] McNemar, Q. Psychological Statistics, Fourth Edition. John Wiley and Sons, Inc., New York, 1969.

Statistical significance at the 0.10 level means that a difference as large as that observed between two conditions can be expected by chance with a probability of 0.10. Therefore, it is likely that the postulated mechanism (for example, day/night) is responsible for the observed difference. If statistical significance is not present, the differences observed are more likely chance.

4.4 THE RELATIVE RISK FACTOR (RRF) ON SELECTED POINTS

The Design Manual makes use of an index, the Relative Risk Factor (RRF). It takes into consideration the mean and standard deviation of vessel tracklines, ship dimensions, ship aspect, and channel width to produce a number which is proportional to the probability of grounding for the simulated conditions. The RRF is operationally defined by the sample calculation in Table 3 which is taken from the Design Manual, Section 2. That report contains an extensive discussion of that index.

The index is not reported for each data line. Rather values were selected which represent the greatest risk encountered in each region of the simulated waterway. The regions were defined by the maneuvers required during the transit: turning, recovery, and trackkeeping. The turn region was considered to extend approximately 0.5 nm from the turn apex in both directions. Recovery (the process of bringing the vessel onto the desired trackline after a maneuver, for the vessel and speed used in this experiment), was assumed to require approximately 0.7 nm after the maneuver. The trackkeeping regions were those areas in which the vessel was neither maneuvering nor recovering from a maneuver.

The channel used in the experiment was divided into five regions. In order of occurrence in the transit, they were (1) recovery to centerline without crosscurrent, (2) trackkeeping without crosscurrent, (3) turn pullout, (4) recovery with crosscurrent, and (5) trackkeeping with crosscurrent.

4.5 THE RELATIVE RISK FACTOR FOR THE WATERWAY (RRFW)

It is useful both for experimental and practical purposes to be able to characterize the performance of an arrangement of aids to navigation throughout a waterway by a single number or index. Thus, a performance measure new to the Waterway Study has been used in this report: the Relative Risk Factor for the Waterway (RRFW).[7] The concept comes from system engineering where the reliability of a system is taken to be the product of the reliabilities of system components. Since the RRF is assumed to be proportional to the probability of grounding in a region; that is, component failure; (1-RRF) is used to represent the "reliability" of each "component". The product of the (1-RRF) for n regions is (1-RRFW).

$$(1\text{-RRFW}) = (1\text{-RRF1})(1\text{-RRF2}) \ldots (1\text{-RRFn})$$

[7]James W. Gynther suggested this measure. The BENEFITS MEASURE task of the Waterway Study highlighted the need for a measure representing a complete transit.

TABLE 3. SAMPLE CALCULATION OF RELATIVE RISK FACTOR (RRF) IN THE RECOVERY REGION

SHIP PARAMETERS

Ship size	30,000 dead weight tons
Ship length	590 feet
Ship beam	85 feet
Crosstrack current velocity	0.25 feet
Transit speed	6 knots
B' (feet)	54.79 feet

CHANNEL PARAMETERS

Channel width	500 feet

SAMPLE CALCULATION OF RRF: Crab angle, 2-5 degrees; gated aids; day

[(W/2) - (MN) - (B')]/(SD) = (NS)
[(500/2) - (97) - (54.79)]/(34) = (2.89)

[(W/2) + (MN) - (B')]/(SD) = (NP)
[(500/2) + (97) - (54.79)]/(34) = (8.59)

(PS) + (PP) = (RRF)
(0.0019) + (0.0000) = (0.0019)

reminder:
W: channel width
MN: mean
B': adjusted beam/2
SD: standard deviation
NS: SDs to starboard
NP: SDs to port
PS: prob to starboard
PP: prob to port
RRF: relative risk factor

The concept is further described by a sample calculation in Table 4. Note that, like the regional RRF value, RRFW is a relative measure of performance.

TABLE 4. SAMPLE CALCULATION OF WATERWAY RELATIVE RISK FACTOR (RRFW)

$$1\text{-RRFW} = (1\text{-RRF1})(1\text{-RRF2}) \ldots (1\text{-RRFn})$$

For Scenario 1: three turn buoy, gated aids
RRF values by region are taken from Table 7

$$1\text{-RRFW} = (1-0.0000)(1-0.0000)(1-0.2389)(1-0.1379)(1-0.0764)$$
$$1\text{-RRFW} = 0.6060$$
$$\text{RRFW} = 1-0.6060$$
$$\text{RRFW} = 0.3940$$

Section 5

EXPERIMENTAL RESULTS

5.1 INTRODUCTION

The effects of arrangement of aids and view of land were assessed by comparing piloting performance in the two (or three) scenarios which represented the effect. The characteristics of the experimental scenarios are summarized in Table 5. Each scenario is further described by a chartlet in Appendix B. Performance in each single scenario is presented as a combined plot in Appendix D. Comparisons between scenarios corresponding to the effects of interest are summarized in Table 6. Each comparison is presented as a comparison plot in Appendix E.

As an overview of the results, the comparison plots and the statistical tests showed the preferred, gated arrangement to be superior in at least some regions of the channel to all the low density, staggered arrangement, whatever the land. The plots and tests also revealed a special effect of the points of land in Scenarios 6 and 7. This effect is discussed in Section 5.3.2 and in 7.3. However, the plots and tests did not generally reveal the variations in visual environment/landmass. This was probably because (1) enough information was available even in the least supportive conditions, to allow the pilots to stay within the boundaries of the channel; and (2) the likelihood of identifying significant differences in means decreases as standard deviations (which were often large) increase. Statistical significance in standard deviation is pointed out in the discussion wherever it is relevant. The relative risk factor (RRF) is more sensitive than the statistical tests and does show differences. Therefore, the emphasis throughout this report is on the RRF and the waterway relative risk factor (RRFW), rather than on the comparison plots and statistical comparisons.

5.2 AID ARRANGEMENTS AND A REPRESENTATIVE VISUAL ENVIRONMENT

5.2.1 <u>Comparison of Aid Arrangements: Gated Versus Staggered</u>

The first objective of the data analysis was to determine whether the superiority of the gated arrangement found in previous work also appears in the present results. This was accomplished by comparing performance in the two conditions that were carried over from Phase II studies. Scenario 1 employed an aids-only visual data base that was used in the Phase II experiments. It had the preferred aid configuration of Phase II: three buoys in the turn and long-spaced gates in the straightaway. See Appendix B for the chartlet for Scenario 1. It was run with the same wind, current, no bank effect, and slow ship speed as in the earlier experiments. It was run under daytime conditions. Scenario 2 was run with the lowest density of buoys that was evaluated in Phase II: one buoy at the inside apex of the turn and long-spaced staggered buoys in the straightaway. All other conditions for this scenario were the same as those for Scenario 1.

TABLE 5. EXPERIMENTAL SCENARIOS

Scenario	Aids	Density	Relative Bearing	Distance	Day/Night
		Targets of Opportunity (TOOs) in Visual Surround			
Objective: Familiarization					
FAM	3-buoy turn, gated buoys	high, cultural objects	all around	within 1.5 nm*	day
Objective: Evaluation of Aid Arrangements					
1	3-buoy turn, gated buoys	none	none	none	day
2	1-buoy turn, staggered buoys	none	none	none	day
Objective: Evaluation of the Visual Environment: Density of Objects					
3	1-buoy turn, staggered buoys	low, landmass	all around	within 1.5 nm	day
A Representative Visual Environment					
4	1-buoy turn, staggered buoys	moderate, cultural objects	all around	within 1.5 nm	day
5	1-buoy turn, staggered buoys	high, cultural objects	all around	within 1.5 nm	day
Objective: Evaluation of Visual Environment: Relative Bearing of Objects					
6	1-buoy turn, staggered buoys	moderate, cultural objects	ahead setup, abeam pullout	within 1.5 nm	day
7	1-buoy turn staggered buoys	moderate, cultural objects	abeam setup, aft pullout	within 1.5 nm	day
Objective: Evaluation of Visual Environment: Distance					
8	1-buoy turn, staggered buoys	moderate, cultural objects	all around	within 2.5 nm	day
Objective: Evaluation of Visual Environment: Day/Night					
9	1-buoy turn, staggered buoys	moderate, cultural lights	all around	within 1.5 nm	night

*nm is nautical mile

TABLE 6. COMPARISONS BETWEEN EXPERIMENT SCENARIOS

Objective	Scenarios	Text Section	Page
Aid Arrangements	1 vs 2	5.2.1	E-3
Representative Visual Environment	2 vs 4	5.2.2	E-4
Density of Objects	4 vs 3, 4 vs 5	5.3.1	E-5, E-6
Relative Bearing of Objects	4 vs 6, 4 vs 7	5.3.2	E-7, E-8
Distance	4 vs 8	5.3.3	E-9
Day/Night	4 vs 9	5.3.4	E-10
Preferred Arrangement	1 vs 2 ... 9	5.4	E-3 E-11 thru E-17
Aids-Only Conservatism	4 vs 2	6.2	E-4

Performance for the gated and staggered buoy arrangements with no view of land (Scenarios 1 and 2, respectively) is shown in Table 7. The RRFW for the gated-buoy waterway is considerably lower than that for the waterway marked by staggered buoys. Standard deviation of the trackline was lower in the gated condition in all regions of the waterway, especially during trackkeeping prior to the turn and recovery after the turn where there were statistically significant differences. The mean trackline also tended to be closer to the centerline for the gated buoy condition than for the staggered condition. The superiority of the preferred arrangement has carried over to the new simulator and the new shiphandling conditions.

5.2.2 Effect of a Representative Visual Environment: Staggered Aids-Only Versus Aids Plus Visual Environment

As suggested earlier, it is possible that the RRF or RRFW associated with the staggered (low density) buoy arrangement is overestimated when it is based on performance in conditions such as those in Scenario 2 of this study. Marked channels are often within sight of land, and the additional cues thus provided may augment the effectiveness of low density buoyage. It is of interest, then, to compare performance observed for waterways with no view of land with that obtained with a visual surround that is more representative of that generally encountered in pilotage waters. Scenario 4 was selected as a representative visual environment. The channel was flanked by landmasses at a distance of within 1.5 nm. A moderate number of structures were located near the shoreline on both sides.

Table 8 contains piloting performance data for waterways marked by staggered buoys with no view of land (Scenario 2) and with a representative visual environment (Scenario 4). The RRFW for the representative waterway is considerably less than that for the waterway with no view of land. This appears to have been due in large part to the difference in RRF for the turn pullout arising from the smaller deviation from centerline observed in Scenario 4, even though the difference is not supported by statistical significance. The overall performance indicates that the visual surround can in fact enhance the effectiveness of aids to navigation.

5.3 EVALUATION OF FEATURES OF THE VISUAL ENVIRONMENT

If the finding that the visual environment can augment the effectiveness of aids to navigation is to have practical utility in waterway design or evaluation, the elements of visual surround that contribute to improved performance must be identified. Therefore, various features of the visual scene were varied systematically in order to examine their effects. Each is described in the sections to follow.

5.3.1 Density of Objects

The effect of the density of objects in the visual environment was assessed by comparing performance for the representative visual scene (Scenario 4) with performance with other visual environments which differed with respect to the density of objects in the scene. Figure 3 illustrates the concept, but is not actually taken from the visual data base. Scenario

TABLE 7. COMPARISON OF GATED BUOY ARRANGEMENT (SCENARIO 1) WITH STAGGERED ARRANGEMENT (SCENARIO 2) (REFERENCE PAGE E-3)

Scenario 1		Scenario 2	
Recovery without crosscurrent[1]			
MN[2]	21.40	MN	20.10
SD[3]	21.56	SD	45.70
RRF[4]	0.0000	RRF	0.0000
Trackkeeping without crosscurrent*			
MN	-10.89	MN	32.72
SD	30.77	SD	79.33
RRF	0.0000	RRF	0.0151
Turn pullout			
MN	150.24	MN	174.82
SD	45.83	SD	72.55
RRF	0.2389	RRF	0.4562
Recovery with crosscurrent*			
MN	143.83	MN	161.97
SD	47.31	SD	49.96
RRF	0.1379	RRF	0.2514
Trackkeeping with crosscurrent			
MN	91.36	MN	39.65
SD	72.80	SD	84.59
RRF	0.0764	RRF	0.0356
WATERWAY Relative Risk Factor[5]			
RRFW	0.3940	RRFW	0.6133

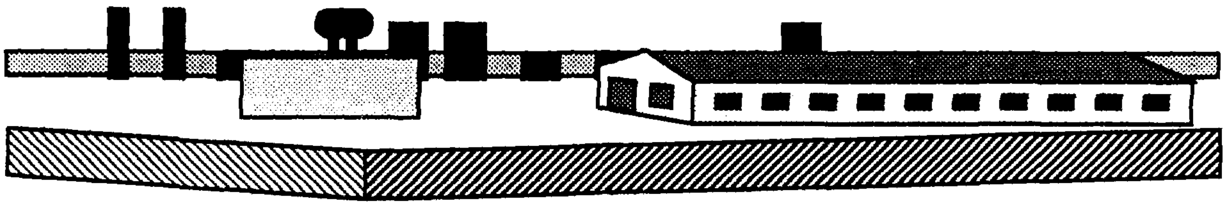
*Significant difference(s) in SD (at the 0.1 level) in this region.

NOTES:
1. The selection of the data from regions of the channel is described in Section 4.4 of this report.
2. Means (MN) are expressed as feet from the channel centerline. Positive values are to starboard.
3. Standard deviations (SD) are in feet.
4. Relative Risk Factor (RRF) is described briefly in Section 4.4 of this report and extensively in the Design Manual.
5. The Waterway Relative Risk Factor (RRFW) is described in Section 4.5

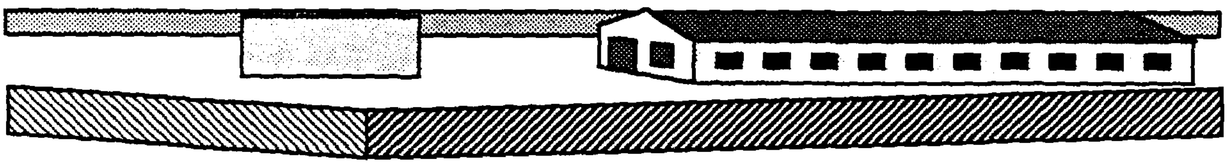
TABLE 8. COMPARISON OF STAGGERED BUOY ARRANGEMENT WITHOUT LAND (SCENARIO 2) WITH REPRESENTATIVE VISUAL SURROUND (SCENARIO 4) (REFERENCE PAGE E-4)

Scenario 2		Scenario 4	
Recovery without crosscurrent[1]			
MN[2]	20.10	MN	23.69
SD[3]	45.70	SD	48.60
RRF[4]	0.0000	RRF	0.0001
Trackkeeping without crosscurrent			
MN	32.72	MN	8.56
SD	79.33	SD	67.52
RRF	0.0151	RRF	0.0023
Turn pullout			
MN	174.82	MN	141.20
SD	72.55	SD	71.26
RRF	0.4562	RRF	0.2776
Recovery with crosscurrent			
MN	161.97	MN	125.41
SD	49.96	SD	76.29
RRF	0.2514	RRF	0.1814
Trackkeeping with crosscurrent			
MN	39.65	MN	70.56
SD	84.59	SD	83.09
RRF	0.0356	RRF	0.0675
WATERWAY Relative Risk Factor[5]			
RRFW	0.6133	RRFW	0.4499

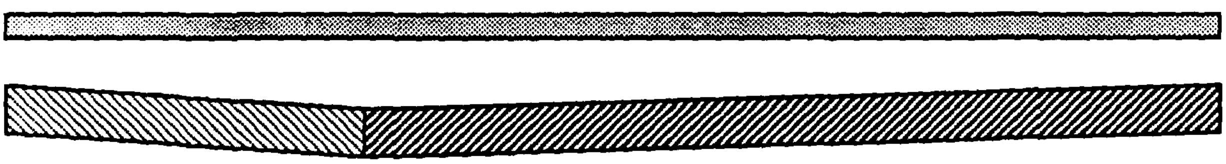
NOTES:
1. The selection of the data from regions of the channel is described in Section 4.4 of this report.
2. Means (MN) are expressed as feet from the channel centerline. Positive values are to starboard.
3. Standard deviations (SD) are in feet.
4. Relative Risk Factor (RRF) is described briefly in Section 4.4 of this report and extensively in the Design Manual.
5. The Waterway Relative Risk Factor (RRFW) is described in Section 4.5



Generic Land (High Density)
(Eye Height Exaggerated)



Generic Land (Moderate Density)
(Eye Height Exaggerated)



Generic Empty Land (Low Density)
(Eye Height Exaggerated)

Figure 3: Density of Shore Structures

3 provided a visual environment with a minimum of objects. The channel was surrounded with a low-lying landmass, compatible with the velocity of the current and lack of bank effects of the experimental conditions carried over from Phase II. The landmass varied in contour and color, but contained none of the objects found in the representative visual scene (Scenario 4). It thus provided some relative motion cues lacking in the earlier experiments. Scenario 5 provided a high density of objects by adding to those in Scenario 4. Distant objects placed behind shoreline objects increased the apparent depth of field and provided range-like relative motion cues. Some discrete objects appeared on the chart and, therefore, could be used for bearings if the pilot chose to use this technique.

Data for scenarios that varied with respect to the density of objects in the visual environment appear in Table 9. The RRFs for the waterways containing moderate and high densities of objects (Scenarios 4 and 5, respectively) were both considerably lower than that for the waterway with low object density (Scenario 3); moderate and high densities seem not to differ from one another, however. Examination of the RRFs for individual sections of the waterways reveals that the differences in RRFW were due primarily to the significantly higher standard deviation in the turn pullout in the low density condition. These data indicate that piloting performance in the presence of a moderate density of objects in the visual scene can be expected to be superior to that observed when there are few objects, but that increases in the density of the surrounding objects beyond a moderate level will not necessarily produce additional improvements.

5.3.2 Relative Bearing of Objects

The effect of relative bearing of visual objects on piloting performance was investigated by comparing performance in the representative visual scene (Scenario 4) with performance in two other scenarios, each of which contained only a portion of the representative visual surround (see Figure 4). Again, this figure is meant to illustrate the concept and is not taken from the simulator data base. The chartlets in Appendix B are to scale with the data base. In Scenario 6, the land and objects to the outside of the turn were retained; the scenario thus represented situations in which a channel approaches land and turns to avoid it. In Scenario 7, land and objects to the inside of the turn were retained; this scenario represented situations in which a channel turns around a point of land.

The results for conditions comprising the relative bearing comparison are shown in Table 10. RRFs for the waterways having land to the outside of the turn only (Scenario 6) and to the inside of the turn only (Scenario 7) were lower than that for the waterway with land all around. The direction of the difference was surprising, even though it was not supported by statistical significance, since the visual scenes employed in Scenarios 6 and 7 contain no objects that were not also present in Scenario 4. Risk associated with the partial visual surrounds was expected therefore to be equal to or greater than that for the complete scene.

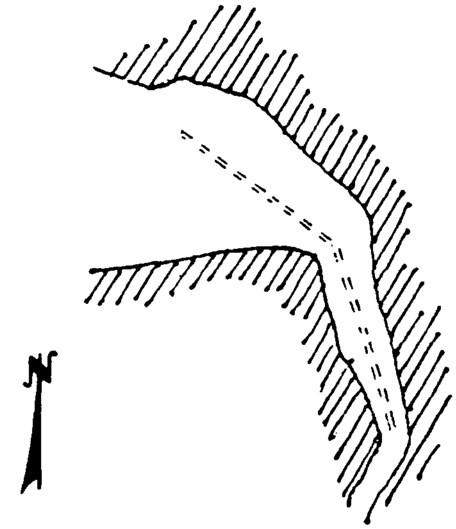
A plausible explanation for this result is found in the way in which the partial visual scenes were generated. The chartlets for Scenarios 6 and 7 show that in both cases the elimination of part of the shoreline resulted in

TABLE 9. COMPARISON OF MODERATE-DENSITY SHORE STRUCTURES (SCENARIO 4) WITH LOW DENSITY (SCENARIO 3) AND HIGH DENSITY (SCENARIO 5) SHORE STRUCTURES (REFERENCE PAGES E-5 AND E-6)

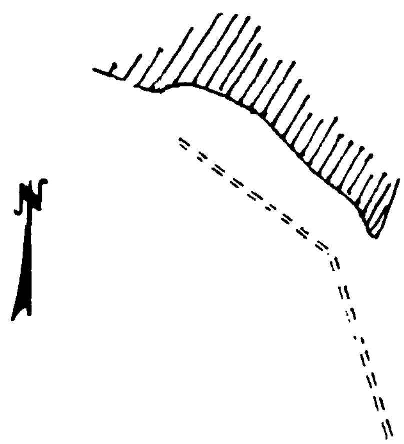
Scenario 3		Scenario 4		Scenario 5	
Recovery without crosscurrent[1]					
MN[2]	14.89	MN	23.69	MN	26.84
SD[3]	40.77	SD	48.60	SD	31.72
RRF[4]	0.0000	RRF	0.0001	RRF	0.0000
Trackkeeping without crosscurrent					
MN	-6.61	MN	8.56	MN	19.25
SD	67.71	SD	67.52	SD	56.73
RRF	0.0023	SD	0.0023	SD	0.0005
Turn pullout*					
MN	164.09	MN	141.20	MN	133.45
SD	117.41	SD	71.26	SD	70.49
RRF	0.4379	RRF	0.2776	RRF	0.2420
Recovery with crosscurrent**					
MN	137.00	MN	125.41	MN	126.02
SD	103.99	SD	76.29	SD	95.19
RRF	0.2884	RRF	0.1814	RRF	0.2331
Trackkeeping with crosscurrent					
MN	37.27	MN	70.56	MN	51.27
SD	76.39	SD	83.09	SD	77.10
RRF	0.0204	RRF	0.0675	RRF	0.0314
WATERWAY Relative Risk Factor[5]					
RRFW	0.6091	RRFW	0.4499	RRFW	0.4372

*Significant difference(s) in SD between Scenarios 3 and 4 in this region.
**Significant difference(s) in SD between Scenario 4 and Scenarios 3 and 5 in this region.

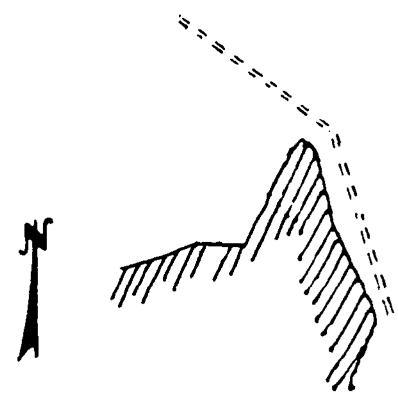
NOTES:
1. The selection of the data from regions of the channel is described in Section 4.4 of this report.
2. Means (MN) are expressed as feet from the channel centerline. Positive values are to starboard.
3. Standard deviations (SD) are in feet.
4. Relative Risk Factor (RRF) is described briefly in Section 4.4 of this report and extensively in the Design Manual.
5. The Waterway Relative Risk Factor (RRFW) is described in Section 4.5



LAND ALL AROUND



LAND - CHANNEL APPROACH - AVOIDING LAND



LAND - CHANNEL APPROACH - TURNING AROUND POINT

Figure 4. Relative Bearing of Land From Turn

TABLE 10. COMPARISON OF LAND ALL AROUND (SCENARIO 4)
WITH LAND ABEAM AT TURN PULLOUT (SCENARIO 6)
AND LAND ABEAM AT TURN SETUP (SCENARIO 7)
(REFERENCE PAGES E-7 AND E-8)

Scenario 4		Scenario 6		Scenario 7	
Recovery without crosscurrent[1]					
MN[2]	23.69	MN	13.77	MN	31.36
SD[3]	48.60	SD	40.02	SD	45.78
RRF[4]	0.0001	RRF	0.0001	RRF	0.0001
Trackkeeping without crosscurrent[1]					
MN	8.56	MN	-11.81	MN	16.68
SD	67.52	SD	64.37	SD	52.29
RRF	0.0023	SD	0.0015	SD	0.0002
Turn pullout					
MN	141.20	MN	125.35	MN	117.90
SD	71.26	SD	52.06	SD	45.91
RRF	0.2776	RRF	0.1335	RRF	0.0778
Recovery with crosscurrent					
MN	125.41	MN	119.67	MN	136.20
SD	76.29	SD	70.44	SD	70.54
RRF	0.1814	RRF	0.1423	RRF	0.2005
Trackkeeping with crosscurrent					
MN	70.56	MN	77.19	MN	84.99
SD	83.09	SD	85.45	SD	72.89
RRF	0.0675	RRF	0.0845	RRF	0.0656
WATERWAY Relative Risk Factor[5]					
RRFW	0.4499	RRFW	0.3206	RRFW	0.3113

NOTES:
1. The selection of the data from regions of the channel is described in Section 4.4 of this report.
2. Means (MN) are expressed as feet from the channel centerline. Positive values are to starboard.
3. Standard deviations (SD) are in feet.
4. Relative Risk Factor (RRF) is described briefly in Section 4.4 of this report and extensively in the Design Manual.
5. The Waterway Relative Risk Factor (RRFW) is described in Section 4.5

the creation of "points" of land adjacent to the channel. Such "points" (as they were referred to by the pilots) are very salient features in the real-world, and their proximity to the turn evidently made them useful TOOs. This explanation is supported by the data for individual regions of the waterways. It is clear that the superiority of Scenarios 6 and 7 was limited to the turn pullout, the channel section closest to the "points". Performance both after and prior to this region is nearly identical in all three conditions. Thus, it appears that this manipulation provided more information about the effect of salient objects near turns than it did about the effects of relative bearing of shoreline. This issue is discussed further in Sections 6 and 7.

5.3.3 Distance

The effect of distance was assessed by comparing performance in the representative visual environment to performance observed when the same land and objects were placed at a greater distance. In Scenario 8, the landmasses were located within 2.5 nm from the edges of the channel, as compared with 1.5 nm for Scenario 4.

Performance data pertaining to the effect of the distance of objects from the waterway are given in Table 11. The waterway surrounded by objects within 1.5 nm was associated with a somewhat lower risk than the waterway with objects within 2.5 nm. The only significant differences between the two conditions occurred at the start of the recovery maneuver. These results suggest that the relative motion effect, the magnitude of which is determined by the distance from the observer of the visual surround, is most important as a pilot begins to "steady up" after a turn.

5.3.4 Day/Night

The effect of day/night was demonstrated by comparing performance in the representative visual scene (Scenario 4) with performance with the same visual scene under night conditions. Scenario 9 was a nighttime version of Scenario 4, with cultural objects along the shore replaced by fixed white and yellow lights.

Data reflecting day/night differences in piloting performance are shown in Table 12. RRFW at night (Scenario 9) is considerably greater than that for daylight (Scenario 4). Although comparisons between the scenarios within channel regions revealed no statistically significant differences, it is clear from the RRFs that the greater risk in Scenario 9 was due in part to the fact that the average trackline was further from the centerline at night than it was in daylight during the turn pullout and recovery. This suggests that in daylight pilots may have used the vessel's apparent distance from the shorelines (less visible in the night scene) as a means of judging their crosstrack position.

5.4 SUMMARY OF RESULTS

The results discussed so far can be briefly summarized.

- First, the superiority of gated over staggered buoy arrangements for aids-only conditions was demonstrated.

TABLE 11. COMPARISON OF SHORE STRUCTURES WITHIN 1.5 NM (SCENARIO 4) WITH SHORE STRUCTURES WITHIN 2.5 NM (SCENARIO 8) (REFERENCE PAGE E-9)

Scenario 4		Scenario 8	
Recovery without crosscurrent[1]			
MN[2]	23.69	MN	17.05
SD[3]	48.60	SD	37.87
RRF[4]	0.0001	RRF	0.0000
Trackkeeping without crosscurrent			
MN	8.56	MN	-0.86
SD	67.52	SD	64.30
RRF	0.0023	RRF	0.0013
Turn pullout			
MN	141.20	MN	133.08
SD	71.26	SD	80.23
RRF	0.2776	RRF	0.2676
Recovery with crosscurrent*			
MN	125.41	MN	138.11
SD	76.29	SD	80.87
RRF	0.1814	RRF	0.2389
Trackkeeping with crosscurrent			
MN	70.56	MN	49.78
SD	83.09	SD	88.45
RRF	0.0675	RRF	0.0533
WATERWAY Relative Risk Factor [5]			
RRFW	0.4499	RRFW	0.4730

*Significant difference(s) in SD in this region.

NOTES:
1. The selection of the data from regions of the channel is described in Section 4.4 of this report.
2. Means (MN) are expressed as feet from the channel centerline. Positive values are to starboard.
3. Standard deviations (SD) are in feet.
4. Relative Risk Factor (RRF) is described briefly in Section 4.4 of this report and extensively in the Design Manual.
5. The Waterway Relative Risk Factor (RRFW) is described in Section 4.5

TABLE 12. COMPARISON OF DAYLIGHT (SCENARIO 4) WITH NIGHT (SCENARIO 9) (REFERENCE PAGE E-10)

Scenario 4		Scenario 9	
Recovery without crosscurrent[1]			
MN[2]	23.69	MN	26.93
SD[3]	48.60	SD	37.69
RRF[4]	0.0001	RRF	0.0000
Trackkeeping without crosscurrent			
MN	8.56	MN	11.49
SD	67.52	SD	98.04
RRF	0.0023	RRF	0.0356
Turn pullout			
MN	141.20	MN	160.71
SD	71.26	SD	64.91
RRF	0.2776	RRF	0.3669
Recovery with crosscurrent			
MN	125.41	MN	137.97
SD	76.29	SD	76.47
RRF	0.1814	RRF	0.2266
Trackkeeping with crosscurrent			
MN	70.56	MN	50.23
SD	83.09	SD	75.71
RRF	0.0675	RRF	0.0287
WATERWAY Relative Risk Factor[5]			
RRFW	0.4499	RRFW	0.5413

NOTES:
1. The selection of the data from regions of the channel is described in Section 4.4 of this report.
2. Means (MN) are expressed as feet from the channel centerline. Positive values are to starboard.
3. Standard deviations (SD) are in feet.
4. Relative Risk Factor (RRF) is described briefly in Section 4.4 of this report and extensively in the Design Manual.
5. The Waterway Relative Risk Factor (RRFW) is described in Section 4.5

- Second, it was found that a representative visual surround did augment the effectiveness of the low density arrangement of aids.

- Examination of particular features of the visual scene suggested the presence of nearby land may be less helpful when there are relatively few objects, when the land is distant, or at night.

From a system design/evaluation perspective, it is of interest to consider the extent to which performance with staggered buoys in the presence of various visual environments approximated performance associated with the gated buoy configuration. RRFW values for all of the waterways (scenarios) are presented in Figure 5. The effects of each of the features of the visual environment have been discussed in previous sections. The major result of the comparison of performance in the preferred buoy configuration with that observed for low density buoyage with a view of land is that, despite improvements associated with some of the visual features, piloting performance with the preferred configuration is significantly better than with low density buoyage regardless of the visual environment. Scenarios 6 and 7 appear to be in conflict with this characterization of the results. However, as mentioned in Section 5.3.2, these conditions probably represent a special case. Implications of these results for waterway design and evaluation are considered in Sections 6 and 7.

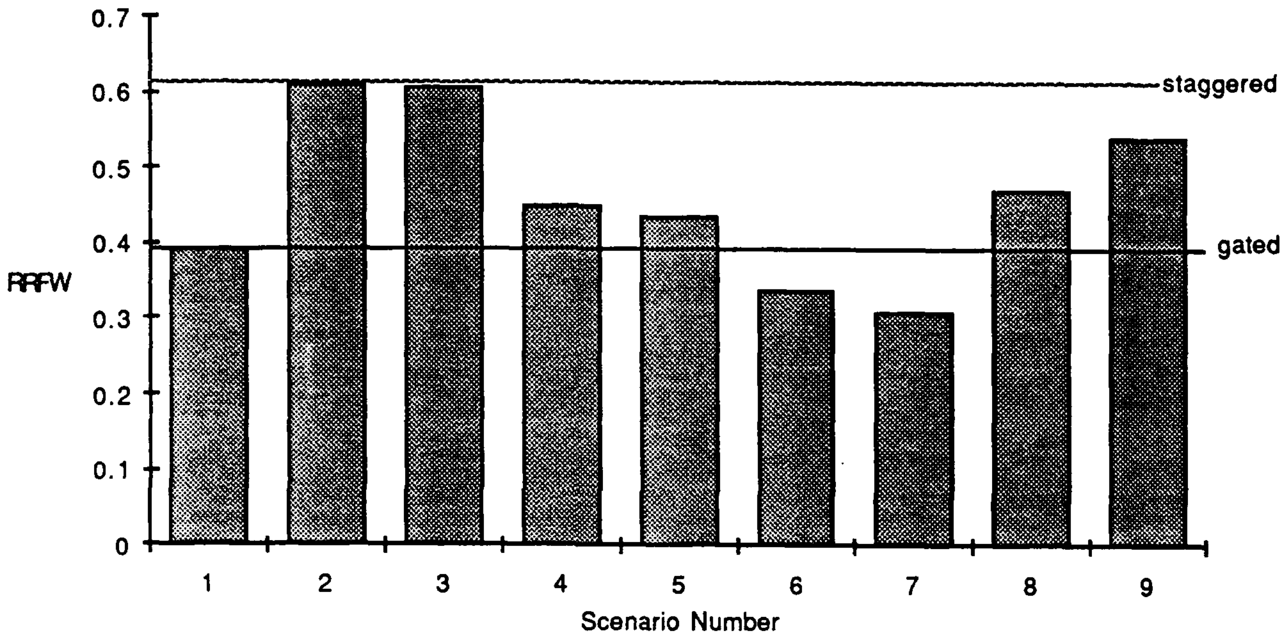


FIGURE 5. WATERWAY RELATIVE RISK FACTOR FOR SCENARIOS 1-9

SECTION 6

PROJECT RESEARCH ISSUES

6.1 INTRODUCTION

Performance data from each simulator experiment in the Waterway project are intended to contribute to the pool of data on which the SRA Systems Design Manual[8] is based. Because this experiment differed from experiments of the earlier phase to a greater or lesser extent in simulator, ship model, pilot group, context effects, etc., data cannot be added to the pool without consideration of the effects of these differences on measured performance. This section first discusses differences between this experiment and those of the earlier phase in experimental conditions and resulting performance. Second, it considers the new data for immediate application to the Manual's present design process.

6.2 SIMULATOR CHARACTERISTICS AND COLLECTED DATA

6.2.1 The United States Coast Guard/Ship Analytics Prototype and the Maritime Training and Research Center Simulators

Phase II experiments were run on the USCG/SA simulator, a simulator that was developed as a low-cost capability to allow the Coast Guard to conduct a large number of experiments. As such, it presented a simple visual scene: a ship bow image and simple aids. The use of this simulator with an aids-only visual scene was supported by a VALIDATION exercise, demonstrating that the simulator was able to match at-sea ship tracks.[9] The simulator was used for a variety of experiments during Phase II and the Phase II Addendum. Selected data from the experiments were used in the Design Manual.

The present experiment was done at the Maritime Training and Research Center (MTRC). The simulator there was developed by Ship Analytics, based on the USCG/SA prototype. The newer simulator is considerably advanced over the earlier one, although it does maintain an overall system compatibility. All changes are in the direction of greater complexity and greater realism. For the present experiment, changes in the visual system are obviously relevant. The capability for greater complexity of scene and the greater horizontal field of view allow for more realistic evaluation of the factors controlling visual piloting. In addition, the ship hydrodynamic model used to determine ship response to control and environmental forces provides a more realistic evaluation of the contribution of ship performance to system performance.

6.2.2 An Opportunity to Evaluate the Conservatism of Aids-Only Simulation

During the earlier phases of the study, when all the simulation was done with an aids-only visual scene, there was concern expressed that this simpler simulation might show unrealistically poor performance for low density buoy arrangements. In turn, this poor performance might lead

[8] op. cit.
[9] op. cit.

designers to discard the alternative of low density arrangements and to substitute higher-density, higher-cost arrangements than necessary. This experiment, done on the more complex MTRC simulator, offered the opportunity to examine the possibility. Scenario 2, as described in Section 5.2, was a low density aids-only arrangement. Scenario 4, also described there, was the same except for the addition of a generic landmass surrounding the channel, with a moderate density of cultural objects scattered on it. Performance data from these two scenarios were described in Section 5.2.2. They are repeated here in Table 13 for this discussion. Scenario 4, the aids-plus-land condition, is somewhat better overall than is Scenario 2, the aids-only condition. The differences are not large or consistent, and, measured by the MN or SD, they never reach statistical significance. (The comparison plot is on page E-4). Measured by the RRF and RRFW, there is an advantage to the aids-plus-land condition. The old data probably do show somewhat overly poor performance for a low density arrangement close to land.

The more interesting question is whether the Manual data resulted in designers' discarding the alternative of low density arrangements when they might have served the purpose. Re-examination of the data in Section 5 will show that the generic landmasses did not allow the low density arrangement to reach the level of performance of the preferred aid arrangements of Scenario 1, the three-buoy turn with a gated straightaway. The effect of aid arrangement is much larger than the effect of land. A designer with a need for a low-risk design would choose the preferred arrangement, even in sight of land.

Probably, the conservatism of aids-only simulation did not lead to overmarking. The exception might be in those special situations where there is a conspicuous, discrete point of land or other TOO quite close to the channel edge. The effect of such a TOO was shown by Scenarios 6 and 7 and discussed in Section 5.3.2. In such a case, the local pilot association may have convinced the designer of its value and he might not have overmarked. The design of waterways using the data from the present experiment is further discussed in Section 7 that follows.

6.2.3 Performance Data From the Two Simulations

One question to be asked regarding the new performance data is how well it matches the earlier pool of data. The degree of match determines the possible uses for the new data. If performance under similar conditions is different, the data can be used quantitatively as a standalone experiment, but cannot be used simply in quantitative comparison with earlier data. The present experiment includes two aids-only scenarios, 1 and 2, that can be compared to earlier simulations. The aid arrangements in these scenarios have been run before. The shiphandling conditions of the earlier experiments were replicated as closely as possible: the present experiment uses the same wind and current as earlier, no bank effects, and a slow ship speed. (The low underkeel clearance of the earlier experiments could not be exactly duplicated. See Item 2 that follows.)

The simulation of Scenarios 1 and 2 differed in a number of ways from earlier simulations of these aid arrangements:

TABLE 13. PERFORMANCE DATA FROM AIDS-ONLY AND AIDS-PLUS-LAND SIMULATIONS (REFERENCE PAGE E-4)

Scenario 2: aids-only		Scenario 4: aids-plus-land	
Recovery without crosscurrent[1]			
MN[2]	20	MN	24
SD[3]	46	SD	49
RRF[4]	0.0000	RRF	0.0001
Trackkeeping without crosscurrent			
MN	33	MN	9
SD	79	SD	68
RRF	0.0151	RRF	0.0023
Turn pullout			
MN	175	MN	141
SD	73	SD	71
RRF	0.4562	RRF	0.2776
Recovery with crosscurrent			
MN	162	MN	125
SD	50	SD	76
RRF	0.2514	RRF	0.1814
Trackkeeping with crosscurrent			
MN	40	MN	71
SD	85	SD	83
RRF	0.0356	RRF	0.0675
WATERWAY Relative Risk Factor [5]			
RRFW	0.6133	RRFW	0.4499

NOTES:
1. The selection of the data from regions of the channel is described in Section 4.4 of this report.
2. Means (MN) are expressed as feet from the channel centerline. Positive values are to starboard.
3. Standard deviations (SD) are in feet.
4. Relative Risk Factor (RRF) is described briefly in Section 4.4 of this report and extensively in the Design Manual.
5. The Waterway Relative Risk Factor (RRFW) is described in Section 4.5

1. The USCG/SA simulator had 182 degrees horizontal field of view forward. The MTRC simulator has an additional screen that shows 26 degrees aft.

2. The ship model available at MTRC for the 30,000 dwt tanker with a midship house differed from the earlier model in that it had more sophisticated hydrodynamics and that it was fully loaded rather than in ballast. The fully loaded ship is more difficult to handle, and, therefore, is more conservative for research purposes.

During data base checkouts at MTRC, the low underkeel clearance of the earlier experiments was increased. The earlier, simpler ship model had reacted to a low underkeel clearance with only a sluggish response to the rudder. The newer, more sophisticated hydrodynamic ship model used at MTRC has a drag effect that slowed the ship during the transit of the channel. The underkeel clearance was increased until the ship was able to maintain a constant 6.8-knot speed through the water for the entire transit. The new underkeel clearance was 19 feet to the 35-foot draft.

3. The aids-only scenarios were run at MTRC during an experimental day that included a familiarization scenario and other experimental scenarios with a complex visual scene. These other scenarios might have resulted in the acquisition of "local knowledge", which was not possible in earlier experiments.

4. The aids-only scenarios were run at MTRC with a longer visibility than the 1-1/2 nautical miles used in the earlier experiments. The longer visibility in this experiment was necessary to allow a fair comparison to the scenarios with a complex visual scene.

Selected data from the two simulations appear in Table 14. The data representing MTRC, Scenarios 1 and 2, appeared earlier in the present report in Section 5.2. The data representing the earlier USCG/SA simulator are taken from the Design Manual, from the tables in Section 5 there. The RRFW, as a performance measure, is new in the present report and is newly calculated from the Manual data. The new data show substantially poorer performance than do the Manual data.

Of the differences between the two simulations listed above, only the ship model could account for poorer performance. The new tanker model's "sea trial" or "offline" performance was different: its advance, transfer, and tactical diameter all increased, relative to the Phase II tanker. These increases make for a generally more difficult-handling ship; they also introduce some very specific difficulties in this experiment. The greater advance means, that to negotiate the turn, the pilot had to issue his rudder commands further from the turn apex than before. The earlier initiation point combined with the low density aid arrangement to decrease the likelihood that he would find the right location. First, he had to estimate his distance to the turn buoy at a greater distance. Second, he lost a powerful source of visual information present in the earlier experiments. The advance of the Phase II tanker placed the proper turn initiation point in line with the inside buoy line. (A chart of the buoy arrangement appears

TABLE 14. PERFORMANCE DATA FROM THE TWO SIMULATIONS

TARGETS OF OPPORTUNITY EXPERIMENT (Maritime Training and Research Center)		DESIGN MANUAL (U.S. Coast Guard/Ship Analytics)	
Scenario 1: three turn buoys, gates		three turn buoys, gates[6]	
Recovery without crosscurrent[1]			
MN[2]	21	MN	7
SD[3]	22	SD	39
RRF[4]	0.0000	RRF	0.0000
Trackkeeping without crosscurrent			
MN	-11	MN	2
SD	31	SD	31
RRF	0.0000	RRF	0.0000
Turn pullout			
MN	150	MN	65
SD	46	SD	33
RRF	0.2389	RRF	0.0002
Recovery with crosscurrent			
MN	144	MN	97
SD	47	SD	34
RRF	0.1379	RRF	0.0019
Trackkeeping with crosscurrent			
MN	91	MN	76
SD	73	SD	50
RRF	0.0764	RRF	0.0084
WATERWAY Relative Risk Factor[5]			
RRFW	0.3940	RRFW	0.0105

TABLE 14. PERFORMANCE DATA FROM THE TWO SIMULATIONS (CONTINUED)

TARGETS OF OPPORTUNITY EXPERIMENT (Maritime Training and Research Center)		DESIGN MANUAL (U.S. Coast Guard/Ship Analytics)	
Scenario 2: one turn buoy, long-spaced staggered		one turn buoy, long-spaced staggered	
Recovery without crosscurrent[1]			
MN[2]	20	MN	6
SD[3]	46	SD	65
RRF[4]	0.0000	RRF	0.0018
Trackkeeping without crosscurrent			
MN	33	MN	5
SD	79	SD	44
RRF	0.0151	RRF	0.0000
Turn pullout			
MN	175	MN	72
SD	73	SD	45
RRF	0.4562	RRF	0.0068
Recovery with crosscurrent			
MN	162	MN	94
SD	50	SD	70
RRF	0.2514	RRF	0.0735
Trackkeeping with crosscurrent			
MN	40	MN	34
SD	85	SD	75
RRF	0.0356	RRF	0.0169
WATERWAY Relative Risk Factor[5]			
RRFW	0.6133	RRFW	0.0970

NOTES:
1. The selection of the data from regions of the channel is described in Section 4.4 of this report.
2. Means (MN) are expressed as feet from the channel centerline. Positive values are to starboard.
3. Standard deviations (SD) are in feet.
4. Relative Risk Factor (RRF) is described briefly in Section 4.4 of this report and extensively in the Design Manual.
5. The Waterway Relative Risk Factor (RRFW) is described in Section 4.5
6. The Design Manual data was not taken from a single continuous transit. Instead, representative data was selected from a number of similar scenarios.

in Appendix B.) This line-up provided pilots with a "range", a specific cue to initiate the turn. The increase in advance took this cue away from the pilots, leaving them with less information on where to initiate the turn.

A close analysis of the contribution of the ship to waterway system performance is planned later in this phase of the Waterway Study. It is expected that this analysis will allow the addition of the new conditions to the revision of the Design Manual for quantitative comparisons. In the interim, guidelines are provided in this report for the immediate consideration of landmass in the performance of low density aids.

6.3 USE OF THE EXPERIMENTAL DATA TO DEVELOP INTERIM GUIDELINES

6.3.1 Effectiveness of Aid Arrangements

Based on earlier experiments and the Design Manual, this experiment was designed with the expectation that a higher-density aid arrangement would be the best performer. Comparison between Scenario 1 (higher-density) and Scenario 2 (lower-density) showed the expected difference. Sample data from these scenarios and a discussion appear in Section 5.2.1. Plotted data appear on page E-3.

The specific objective of the experiment was to evaluate the contribution of landmass to the performance of low density arrangements. Toward this end the low density arrangement of Scenario 2 was repeated with a variety of nearby landmasses. Scenario 2 did result in the poorest performance in the experiment; low density arrangements with landmasses were somewhat better; Scenario 1 was generally the highest performer. Sample data and discussion appear in Section 5.4. Plotted data appear on pages E-11 to E-17.

The guidelines take these relationships into account. The system designer is advised that reliable high performance must be supported by a higher-density arrangement of aids and that landmass and a low density of aids never achieve the performance of such an arrangement. An exception of this degree of conservatism is made in the presence of landmarks.

6.3.2 Landmarks Versus Landmass

The contribution of landmarks or landmass to the navigation process might be:

1. As fixed points to be used for checking bearings, estimating ranges, using pairs of landmarks as ranges, using prominent objects as leading marks, etc.[10]

2. As background for subjective estimates of relative position, relative motion, etc.

3. As something in between, or some combination of these functions.

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[10] R.S. Crenshaw. Naval Shiphandling. 4th Edition, United States Naval Institute, Annapolis, Maryland, Chapter XI, Restricted Water, 1977.

The experiment was designed so that either use was possible. The participating pilots were not instructed to make any particular use of the landmass and objects, but were asked to discuss what they were doing.

The pilots reported that in actual practice, certain points or objects were commonly used by them, or by their associations, as part of "local knowledge" or "local custom" and that these fixed points were highly useful. They felt land in general was not very useful, or was useful only for "judging speed" or "rate of swing". During the experiment, there was no "local custom". They only occasionally reported selecting specific objects or points, and, generally, there was no consistency across pilots in which points were selected. For the most part, they reported using land only as a general background and predicted that its contributions would not influence the ship tracks, which comprise the primary data.

The only points or objects that had an obvious effect on ship tracks were the points of land left in two scenarios when parts of the landmasses were cut away. The intention was to investigate the effects of land at limited relative bearings to the ship's transit. These points of land and their relative bearings are illustrated in Figure 6. The resulting performance in the turn pullout appears in Table 15 in comparison with performance for the preferred and low density aids-only arrangements. Some of the pilots mentioned these points as references ("targets of opportunity"). Apparently, enough pilots used these points, and they contributed enough cues so that the turn pullouts were the best observed. It appears that landmarks off the channel edge can contribute favorably to navigation, even in the difficult turn maneuver. These conditions and the results were discussed earlier in Section 5.3. The fact that these landmarks afforded better performance in nearby regions than even the high density aid arrangement suggests that they might have improved performance even with such aid arrangements.

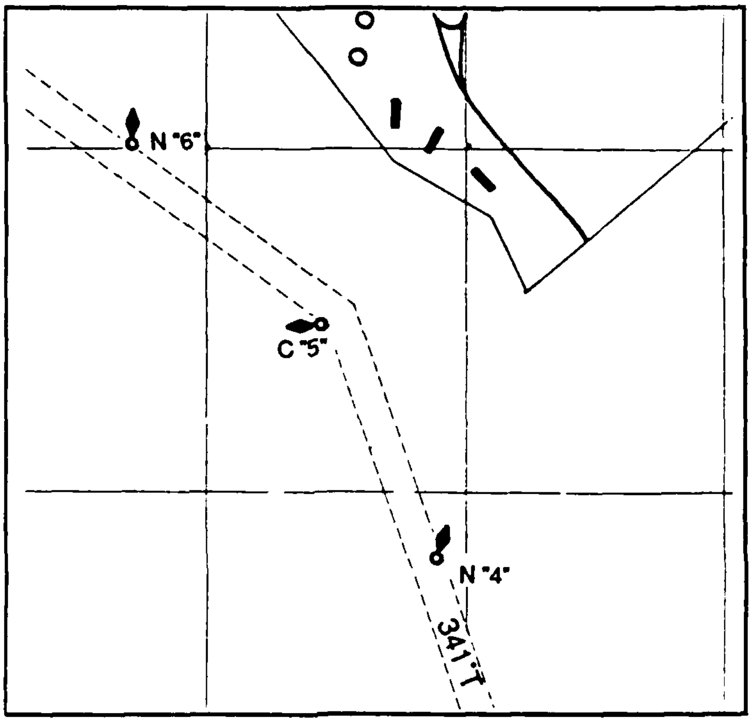
TABLE 15. EFFECT OF LANDMARK WITHIN 0.5 NM[1] OF CHANNEL EDGE ON TURN PULLOUT (RRF)[2]

	PREFERRED ARRANGEMENT	LANDMARK OUTSIDE TURN	LANDMARK INSIDE TURN	LOW DENSITY ARRANGEMENT
RRF	0.2389 (Scenario 1)	0.1335 (Scenario 6)	0.0778 (Scenario 7)	0.4562 (Scenario 2)

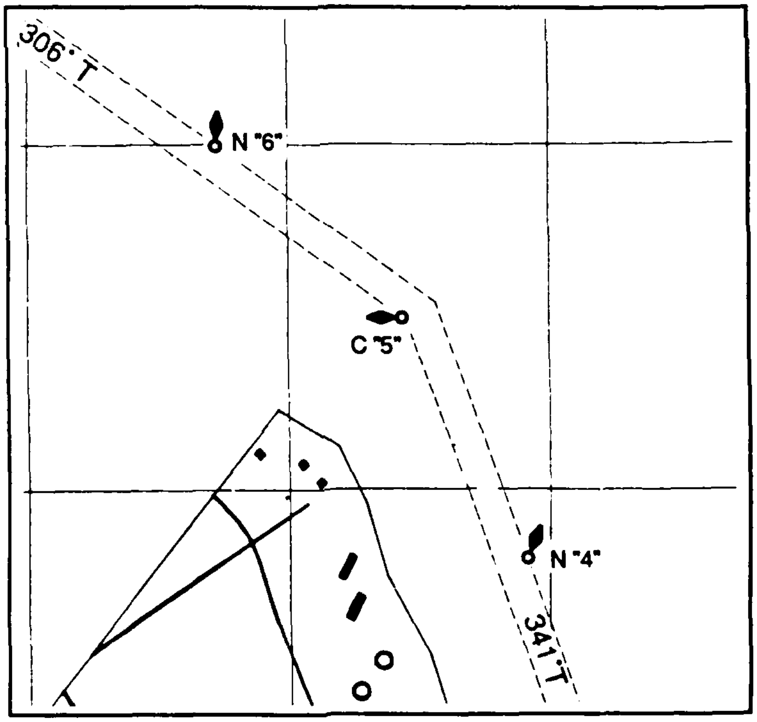
NOTES:

1. NM is nautical miles

2. RRF, or relative risk factor, is discussed in Section 4.4 of this report.



Scenario 6



Scenario 7

Figure 6. Landmarks to Inside and Outside of Turn

In Section 7 it is recommended that the district system designer make a distinction between landmarks and landmass. The Waterway study has never investigated Coast Guard-provided fixed structures off the channel edge. It is recommended that these can be considered equivalent to discrete, conspicuous landmarks. When a landmark/fixed structure is present and certain restrictions are met, the designer is instructed to assume better performance for a region marked by a low density of aids than that indicated by the present Design Manual.

6.3.3 Contribution of Landmass and its Characteristics

Scenario 2 is used as a stand-in within this experimental context for Design Manual performance data. Differences between Scenario 2 and the variety of other conditions evaluated in this experiment are examined by experimental variable and by waterway region. The relationships observed are the basis of the guidelines presented in Section 7 for evaluating the effect of landmass. There, the system designer is first instructed to evaluate performance for a low density arrangement, using the present Design Manual procedure, and then is provided with instructions for qualitatively considering the contribution of landmass.

A sample of performance data for the aids-only condition, Scenario 2, is presented in Table 16. Only three regions of the waterway are represented: the turn pullout, and recovery and trackkeeping with crosscurrent. Only these three are included in the discussion because these regions with the more difficult shiphandling tasks are more likely to show differences among variable levels, and because performance data from these difficult regions are recommended by the Design Manual for more frequent use. Also presented in the table are the effects of landmass and the changes in landmass characteristics that represent the variable of density of objects. These conditions and resulting performance are discussed in Section 5.3.1.

The performance data show some effect of landmass and some effect of density of objects. Such a trend is most apparent in the turn pullout. The mean decreases systematically, causing a corresponding decrease in RRF, despite the large standard deviation in Scenario 3. Apparently, the pilots generally selected objects or found cues that were useful to them in making the turn. An RRF calculated for a low density of aids only would be an over-estimation of risk for a turn pullout in sight of land.

The recovery region shows a decrease in the mean with landmass, but no systematic trend to the standard deviation or to the resulting RRF. The decreased mean and the increased standard deviation are the result of a few tracks to the inside and right of the major cluster of tracks. The effect of landmass on ship tracks is less consistent than in the turn region. Apparently, in this less critical maneuver, fewer pilots selected objects as references or attended to cues provided by the land. Given the greater ambiguity in trend here, a more cautious conclusion is that the RRF for a low density of aids alone only slightly over-estimates the risk of recovery in sight of land.

TABLE 16. EFFECT OF LANDMASS AND OBJECT DENSITY ON PERFORMANCE WITH A LOW DENSITY OF AIDS

	AIDS ONLY (SCENARIO 2)	LANDMASS (SCENARIO 3)	MODERATE DENSITY (SCENARIO 4)	HIGH DENSITY (SCENARIO 5)
Turn Pullout[1]				
MN[2]	175	164	141	133
SD[3]	73	117	71	70
RRF[4]	0.4562	0.4379	0.2776	0.2420
Recovery with Crosscurrent				
MN	162	137	125	126
SD	50	104	76	95
RRF	0.2514	0.2884	0.1814	0.2331
Trackkeeping with Crosscurrent				
MN	40	37	71	51
SD	85	76	83	77
RRF	0.0356	0.0204	0.0675	0.0314

NOTES:

1. The selection of the data from regions of the channel is described in Section 4.4 of this report.
2. Means (MN) are expressed as feet from the channel centerline. Positive values are to starboard.
3. Standard deviations (SD) are in feet.
4. Relative Risk Factor (RRF) is described briefly in Section 4.4 of this report and extensively in the Design Manual.

The performance data for the <u>trackkeeping region</u> show no trend. The RRF calculated for aids alone cannot be said to over-estimate risk in the presence of land.

Table 16 shows an apparent interaction between difficulty of maneuver and benefit from nearby landmass. The aids-only condition shows a steep decrease in RRF values from turn to recovery to trackkeeping; landmass shows generally lower RRF values, but only for the more difficult maneuvers. For the least critical trackkeeping region, landmass had no apparent effect. It appears that the pilots made most use of the landmass to control the precision of the ship tracks when that precision was most critical -- in the turn pullout. As the precision of tracks gets less critical -- from recovery to trackkeeping -- the effect of landmass is less apparent in measured ship track precision.

Performance data illustrating the effect of <u>relative bearing</u> of landmass in relation to the turn, the most critical maneuver, appear in Table 17. The aids-only condition of Scenario 2 is included again as a baseline. The condition of land all around the turn is represented by Scenario 4, which has the same moderate density of objects as Scenarios 6 and 7.

The <u>turn pullout</u> region shows the difference between aids-only and nearby landmass discussed above. It also shows superior performance for conditions with a point of land to the inside or outside of the turn. The means, standard deviation, and RRF values are all low for those conditions. Apparently the conspicuity or saliency of these points meant the pilots were relatively consistent in using them to improve their tracks. In Section 6.3.2 the inferred use of these points was interpreted as evidence of the effectiveness of landmarks near any region. Certainly, RRF values calculated for aids alone over-estimates risk in a turn region when there is nearby landmass.

In the <u>recovery region</u> performance for the condition with land to the outside relative to the last turn, the side of concern to the pilots, is very much like performance with land to both sides. The last condition, with land tc the inside of the turn at set up and well behind the ship in the recovery, is losing its advantage over the aids-only condition. A cautious conclusion is that an RRF for an aids-only condition slightly over-estimates risk in a recovery region with land to both sides or only to the outside of the relevant turn. The aids-only RRF is probably a reasonable estimate of risk when the landmass is well astern.

In the <u>trackkeeping region</u> there is, again, no apparent effect of nearby landmass. The aids-only RRF must be accepted as a reasonable estimate of risk.

Performance data illustrating the effect of <u>distance</u> of landmass from the waterway appear in Table 18. The aids-only scenario is repeated as a baseline. The condition of land within 1.5 nautical miles (nm) of the channel edge is represented by Scenario 4. The new condition here is land within 2.5 nm, represented by Scenario 8.

TABLE 17. EFFECT OF RELATIVE BEARING OF LANDMASS IN RELATION TO TURN

	AIDS ONLY (SCENARIO 2)	ALL AROUND (SCENARIO 4)	OUTSIDE (SCENARIO 6)	INSIDE (SCENARIO 7)
Turn Pullout[1]				
MN[2]	175	141	125	118
SD[3]	73	71	52	46
RRF[4]	0.4562	0.2776	0.1335	0.0776
Recovery with Crosscurrent				
MN	162	125	120	136
SD	50	76	70	71
RRF	0.2514	0.1814	0.1423	0.2005
Trackkeeping with Crosscurrent				
MN	40	71	77	85
SD	85	83	85	73
RRF	0.0356	0.0675	0.0845	0.0656

NOTES:

1. The selection of the data from regions of the channel is described in Section 4.4 of this report.
2. Means (MN) are expressed as feet from the channel centerline. Positive values are to starboard.
3. Standard deviations (SD) are in feet.
4. Relative Risk Factor (RRF) is described briefly in Section 4.4 of this report and extensively in the Design Manual.

TABLE 18. EFFECT OF DISTANCE OF LANDMASS FROM WATERWAY

	AIDS ONLY (SCENARIO 2)	LAND 2.5 NM[1] (SCENARIO 8)	LAND 1.5 NM (SCENARIO 4)
Turn Pullout[2]			
MN[3]	175	133	141
SD[4]	73	80	71
RRF[5]	0.4562	0.2676	0.2776
Recovery with Crosscurrent			
MN	162	138	125
SD	50	81	76
RRF	0.2514	0.2389	0.1814
Trackkeeping with Crosscurrent			
MN	40	50	71
SD	85	88	83
RRF	0.0356	0.0533	0.0675

NOTES:

1. NM: nautical mile

2. The selection of the data from regions of the channel is described in Section 4.4 of this report.

3. Means (MN) are expressed as feet from the channel centerline. Positive values are to starboard.

4. Standard deviations (SD) are in feet.

5. Relative Risk Factor (RRF) is described briefly in Section 4.4 of this report and extensively in the Design Manual.

The turn pullout region shows an effect of landmass but no effect of distance of landmass. Apparently the pilots made use of the landmass in the critical turn pullout, even if that land was at a distance. The RRF calculated for aids alone is an over-estimation of risk with up to a 2.5 nm distance.

The recovery region shows an effect similar to the general effect of landmass described at the beginning of this subsection. With landmass the mean and RRF improve but the standard deviation does not. There is a suggestion in Table 18 that performance may be worse with landmass at the greater 2.5 nm distance than for the closer landmass. However, inspection of Table 16, with variations in landmass at 1.5 nm distance, will show that recovery at 2.5 nm falls within their range. It appears inappropriate to conclude that there is a difference as a function of distance. RRF values calculated for aids only slightly over-estimates risk of recovery up to within 2.5 nm of landmass.

The performance data for the trackkeeping region again show no trend. The RRF calculated for aids alone cannot be said to over-estimate risk in the presence of land.

6.3.4 Nighttime and Shore Lights

Performance data illustrating the effect of nighttime appear in Table 19. Two daytime conditions, the aids-only scenario and the landmass with a moderate density of objects, are included for comparison. For the nighttime condition, Scenario 9, buoys were presented as flashing lights and objects along the shoreline were represented by steady lights. No aids-only/nighttime scenario was included in this experiment. Based on past experiments, such a condition would be expected to have the poorest performance, or highest risk, outside the range of values observed for the conditions that are represented here.

The turn pullout region shows the nighttime condition at an intermediate level of performance or risk. The disadvantage of flashing light rather than buoys is out-weighed by the presence of steady lights on shore. The use of an RRF value calculated for aids-only condition would overestimate risk, day or night.

The recovery region shows land, day or night, resulting in an improvement in mean and in RRF, even though the standard deviation increases. The difference between aids-only/daytime and land/nighttime in RRF is small, but the difference between an aids-only/nighttime scenario and land/night would probably have been greater. RRF values calculated for an aids-only slightly overestimates the risk for regions in sight of land, day or night.

The trackkeeping region shows no consistent effect of land. RRF values calculated for aids only cannot be said to overestimate risk in sight of land, day or night.

TABLE 19. EFFECT OF SHORE LIGHTS AT NIGHT

	AIDS, DAY (SCENARIO 2)	LAND, NIGHT (SCENARIO 9)	LAND, DAY (SCENARIO 4)
Turn Pullout[1]			
MN[2]	175	161	141
SD[3]	73	65	71
RRF[4]	0.4562	0.3669	0.2776
Recovery with Crosscurrent			
MN	162	138	125
SD	50	76	76
RRF	0.2514	0.2266	0.1814
Trackkeeping with Crosscurrent			
MN	40	50	71
SD	85	76	83
RRF	0.0356	0.0287	0.0675

NOTES:

1. The selection of the data from regions of the channel is described in Section 4.4 of this report.
2. Means (MN) are expressed as feet from the channel centerline. Positive values are to starboard.
3. Standard deviations (SD) are in feet.
4. Relative Risk Factor (RRF) is described briefly in Section 4.4 of this report and extensively in the Design Manual.

Section 7

INTERIM GUIDELINES FOR EVALUATING THE CONTRIBUTION OF VISIBLE LAND

7.1 INTRODUCTION

The overall plan for the Waterway Study is to use the findings of the TASK 1 simulator experiments for a revision of the SRA Systems Design Manual[11] under TASK 6 in 1989. This section provides interim guidelines to be used until then in the evaluation of the contribution of nearby landmass to waterway performance. The revision to the Design Manual will benefit from experience with, and reaction to, this present version.

The overall difficulty of the shiphandling task in the Targets of Opportunity experiment was greater than that in the Phase II experiments, on which the Design Manual is based and, therefore, the overall level of measured risk was greater. The difference in overall level means that data from this experiment cannot be added to the Design Manual's pool in a simple way. Instructions here provide for a combination of quantitative and qualitative procedures, that make the best possible immediate use of the findings. The Ship Performance task in this phase of the study is planned to closely examine the contribution of the ship to performance in a waterway. That analysis may justify more quantitative procedures when the Design Manual is revised.

7.2 POSSIBLE OBJECTIVES OF THIS ANALYSIS

The USCG's Aids to Navigation Manual-Administration[12] assumes "Aids to Navigation only supplement natural and man-made landmarks and those other environmental features which provide the mariner with cues to navigate. Consequently, existing geographic composition must be considered throughout the design process." The Design Manual points out generally in "Section 4 Design Guidelines ..." that land and landmarks contribute, but does not provide any guidelines for that contribution.

Based on the new experimental findings, guidelines are provided for the following additions or modifications to the Design Manual's design and evaluation process:

1. The evaluation of the contribution of discrete, conspicuous LANDMARKS close to the channel edge: these landmarks -- or fixed structures -- may justify changes in RRF for the better in nearby regions.

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[11] Smith, M.W., K.L. Marino, and J. Multer Short Range Aids to Navigation Systems Design Manual for Restricted Waterways, (CG-D-18-85, United States Coast Guard, Washington, D.C. 20593 (NTIS AD-A158213).

[12] United States Coast Guard, Aids to Navigation Manual-Administration, COMMANDANT INSTRUCTION M16500.7. U.S. Coast Guard, Washington, D.C. 20593.

2. The evaluation of the contribution of nearby LANDMASS to piloting with a low-density aid arrangement: the evaluation here has both quantitative and qualitative components. RRF values calculated from Design Manual data for low and high-density aid arrangements provide a quantitative range within which performance would be expected to fall. Instructions are provided for a qualitative interpolation within this range, based on the features of the landmass surrounding the waterway.

3. Special recommendations for NIGHTTIME transits: nighttime transits with a low-density aid arrangement and nearby land-based lights can be considered the equivalent of daytime Design Manual data without land and the lower (better) RRF values used.

7.3 PROCEDURES FOR THE ANALYSIS

7.3.1 Preparation

The following steps are a necessary preparation.

1. Evaluate performance in the waterway for aids only, as if there were no visible landmass, landmarks, or structures.

The SRA Design Manual must be used for general guidance in breaking the waterway into regions and in specifying conditions. The Automated Relative Risk Factor Program developed by Ship Analytics, Inc. for the USCG Automated Work Station will simplify the procedure by performing the calculations.

Assuming daytime and unlimited visibility, select or calculate RRF values for both a low and a high density of aids. The values can be organized using the worksheet provided here as Figure 7a. (A sample application appears as Figure 7b). Alternately, the Options Report provided by the Automated Program can be marked to show these results. The low-density value provides a baseline; the high-density value, a limit as to what improved estimates of performance might be expected.

2. Collect information about visible landmass, landmarks, and nearby structures, including USCG - provided aids off the channel edge.

Sources of information include charts, light list, discussions with local USCG staff, pilots and other users, and own experience and photos collected riding the waterway. Both day and night views should be considered. Information on expected frequency of varying levels of visibility will be helpful. See Design Manual Sections 3 and 4.

7.3.2 The Contribution of Landmarks

Examine the waterway region by region for the presence of nearby discrete, conspicious landmarks or fixed structures off the channel edge. Look for structures that meet both the following criteria:

WORKSHEET FOR SUMMARIZING CONTRIBUTIONS OF LANDMARKS/LANDMASS

WATERWAY ____________________

Region RFF	Daytime Low-Density RRF	Contribution of Landmarks/Landmass to RRF	Daytime Higher-Density RRF

Figure 7a. Application

WORKSHEET FOR SUMMARIZING CONTRIBUTIONS OF LANDMARKS/LANDMASS

WATERWAY Port XYZ

Region RFF	Daytime Low-Density RRF	Contribution of Landmarks/Landmass to RRF	Daytime Higher-Density RRF
APP. (REC)	0.0735	Fixed Structure: RRF = 0.0019	0.0019
TURN 1	0.0068	Land/day: 0.0068 > RRF > 0.0002	0.0002
		(Shorelights/Night: RRF = 0.0068)	
Recovery 1	0.0735	Land/day: 0.0735 > RRF > 0.0019	0.0019
TK 1	0.0169	RRF = 0.0169	0.0000

SAMPLE

Figure 7b. Sample Application

a. The pilots must report, or agree that they consistently make use of that landmark/fixed structure. (Note that other users, such as military piloting teams or operators of vessels with low height of eye, may make different use of landmarks.)

b. The landmark/fixed structure must be within 0.5 nm of the channel edge.

For only the region nearest the landmark/structure, better performance can be assumed in one of the following ways, which even seems most appropriate for the candidate region:

a. Include the landmark/structure as the equivalent of a sidemark when specifying the aid arrangement for the region. Select performance data for a higher density of aids.

b. Substitute the RRF of a higher-density of aids for that of a lower density. Make the substitution only for daytime and adequate visibility to see the landmark/structure.

c. If the region has a high-density or high-performing aid arrangement, make note that the RRF may over-estimate risk. Make no change to the RRF.

Note: The 1985 SRA Systems Design Manual on page 5-65 suggests a procedure for aids off the channel edge. The findings of the Targets of Opportunity experiments demonstrated that the procedure was too conservative. It is no longer recommended.

7.3.3 The Contribution of Landmass

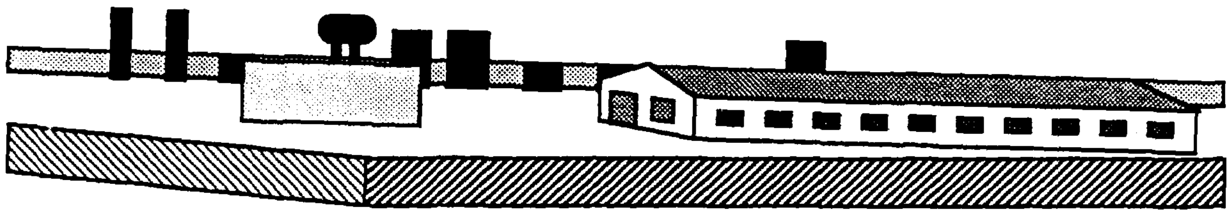
The Targets of Opportunity Experiment examined piloting with a low density of aids and nearby landmass. Landmass varied in the following ways:

- density of cultural objects (see Figure 8)
- relative bearing during turn (see Figure 9)
- distance from turn
- day/night

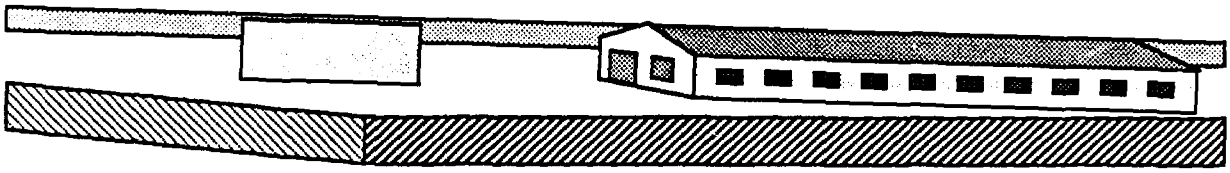
The general findings were that nearby visible land made a meaningful improvement in turn region performance, made only a slight difference in the recovery region, and had no measureable effects in the trackkeeping region.

For a region marked with a low density of aids, instructions are provided below for deciding whether or not the calculated RRF over-estimates risk. Mark the region on the worksheet or on the Options Report.

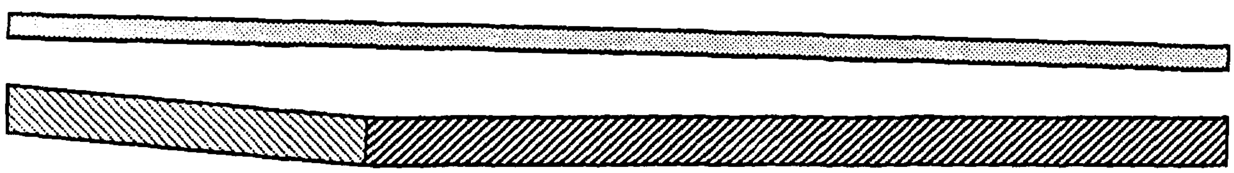
For a region marked with a high density of aids, there is no experimental evidence that nearby landmass improves performance or decreases risk from that estimated by the calculated RRF. No change to RRF is recommended.



Generic Land (High Density)
(Eye Height Exaggerated)

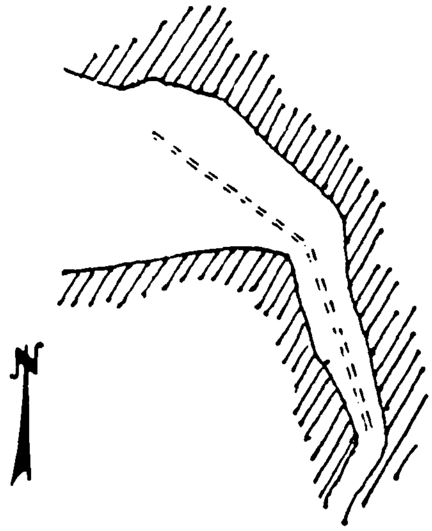


Generic Land (Moderate Density)
(Eye Height Exaggerated)

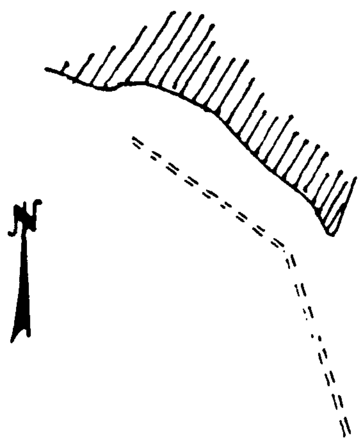


Generic Empty Land (Low Density)
(Eye Height Exaggerated)

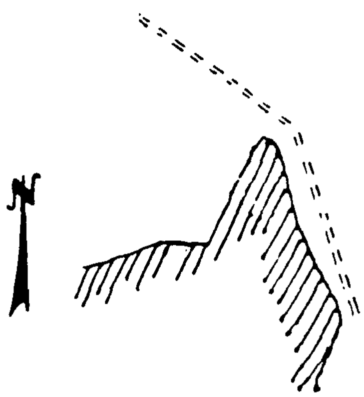
Figure 8: Density of Shore Structures



LAND ALL AROUND



LAND - CHANNEL APPROACH - AVOIDING LAND



LAND - CHANNEL APPROACH - TURNING AROUND POINT

Figure 9. Relative Bearing of Land From Turn

1. For each turn region, examine the nearby landmass and indicate that the RRF for a low density of aids over estimates risk if all following criteria are met:

a. density of objects: land provides fixed points for relative motion cues. More effective if object density is sufficient to show a range-like motion between farther and closer objects as the ship moves.

b. relative bearing: land is all around, or contour of land is such that turn is being made around a point of land to the inside of turn or to avoid land to the outside of the turn.

c. distance: land and sufficient objects are within 2.5 nm of channel edge.

2. For each recovery region, examine the nearby landmass and indicate that the RRF for a low density of aids slightly over-estimates risk if all the following criteria are met:

a. density of objects: land provides fixed points for relative motion cues. More effective if object density is sufficient to show a range-like motion between farther and closer objects as the ship moves.

b. relative bearing: land is all around; or contours are such that land is present to outside of channel, relative to last turn.

c. distance: land and sufficient objects are within 2.5 nm of channel edge.

3. For each trackkeeping region, indicate that the RRF calculated with low density of aids is an appropriate estimate of risk.

7.3.4 Nighttime Transits in View of Land

A finding of the Targets of Opportunity Experiment was that the turn pullout at night in view of shore light was better (lower RRF) than a daytime/aids only condition.

For the very limited circumstances under which all the following criteria are met, the daytime/aid-only baseline values from the Design Manual may be substituted for the nighttime value:

a. for the turn region only

b. fixed lights are visible along the shore

c. lights are all around, or contour of lighted shoreline is such that turn is being made around a point of land or to avoid land

d. a variety of lights are within 2.5 nm of the turn

7.4 RISK MANAGEMENT

The preceding steps have been additions or modifications to the procedures of the Design Manual's "Section 5 Evaluation Procedure ..." The designer can go on to "Section 9 Risk Management Procedures" knowing whether a low-density aid arrangement is afforded a safety margin because of nearby land.

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APPENDIX A

MARINE TRAINING AND RESEARCH CENTER (MTRC) SIMULATOR DESCRIPTION

MTRC SHIPHANDLING SIMULATOR SUBSYSTEMS

Realistic simulation of the total man-ship-environment is a vital component in molding desirable behavior, for both maritime training and in analyzing human operator behavior in research applications. The Maritime Training and Research Center's full mission bridge simulator (See Figure A-1) provides this realistic simulation by means of the following components:

- Navigation Bridge - a full-scale, fully equipped wheelhouse (including radar) from which the simulation is controlled by the mariner (See Figure A-2)

- Control Station - a console from which simulator operators or instructors can start, monitor and terminate simulation exercises, and control other traffic ships, environmental conditions, or ship system failures

- Visual Scene - a large semi-circular screen surrounds the wheelhouse on which is projected a full color Computer Generated Image (CGI) that moves in real-time and displays surrounding geographic/cultural features, aids to navigation, and other traffic ships

- Host Computer - a digital computer which generates video signals to construct the CGI visual scene and required radar PPI information, stimulates various repeaters/indicators on the bridge, and controls the motion of ownship in accordance with its equations of motion

- Classroom - an area utilized by trainees and instructors for a number of functions including formal lectures, presentations of audio/visual material, exercise planning, briefing, monitoring, and post-exercise critique

- Monitoring Station - a remote monitoring location with capabilities which permit trainees to learn from observing the performance of others on the simulator. These features include audio and visual monitoring of persons on the simulator bridge, monitors which display the radar PPI and visual scene as observed in the wheelhouse, and communications equipment

- Graphic Feedback Display - a large screen projection system with a variety of computer graphic applications used in the playback of recorded exercise data to reinforce the on-bridge training. Ship control parameters, such as rudder angle and engine RPM, and the actual track of the simulator ownship, can be presented to trainees in graphic format for post-exercise critique of their individual performance

Operation of the various control equipment provides inputs to the Host Computer which then directs the visual and radar generation subsystems to display apparent motion as described previously. The computer also drives the various indicators on the bridge to display information showing the

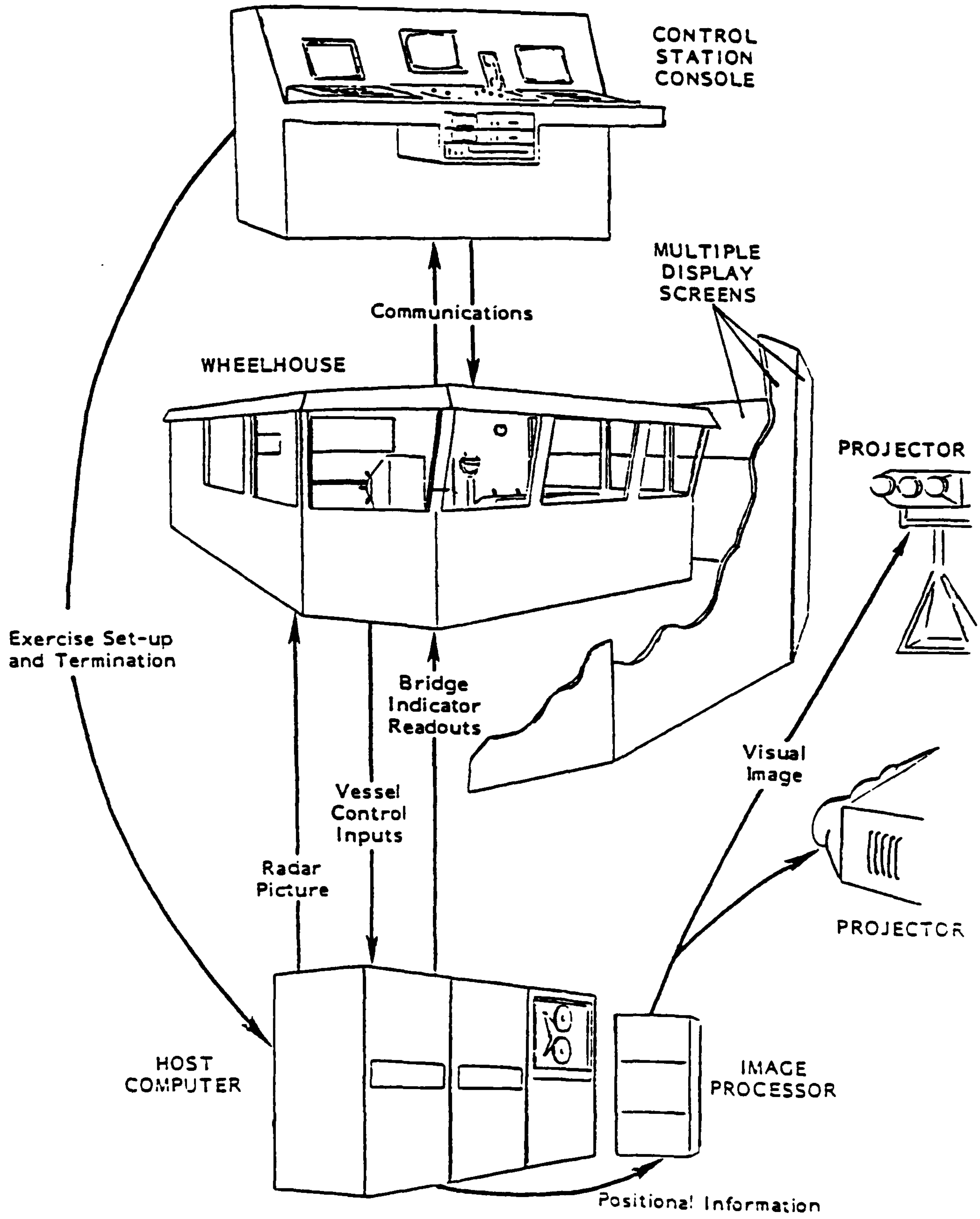
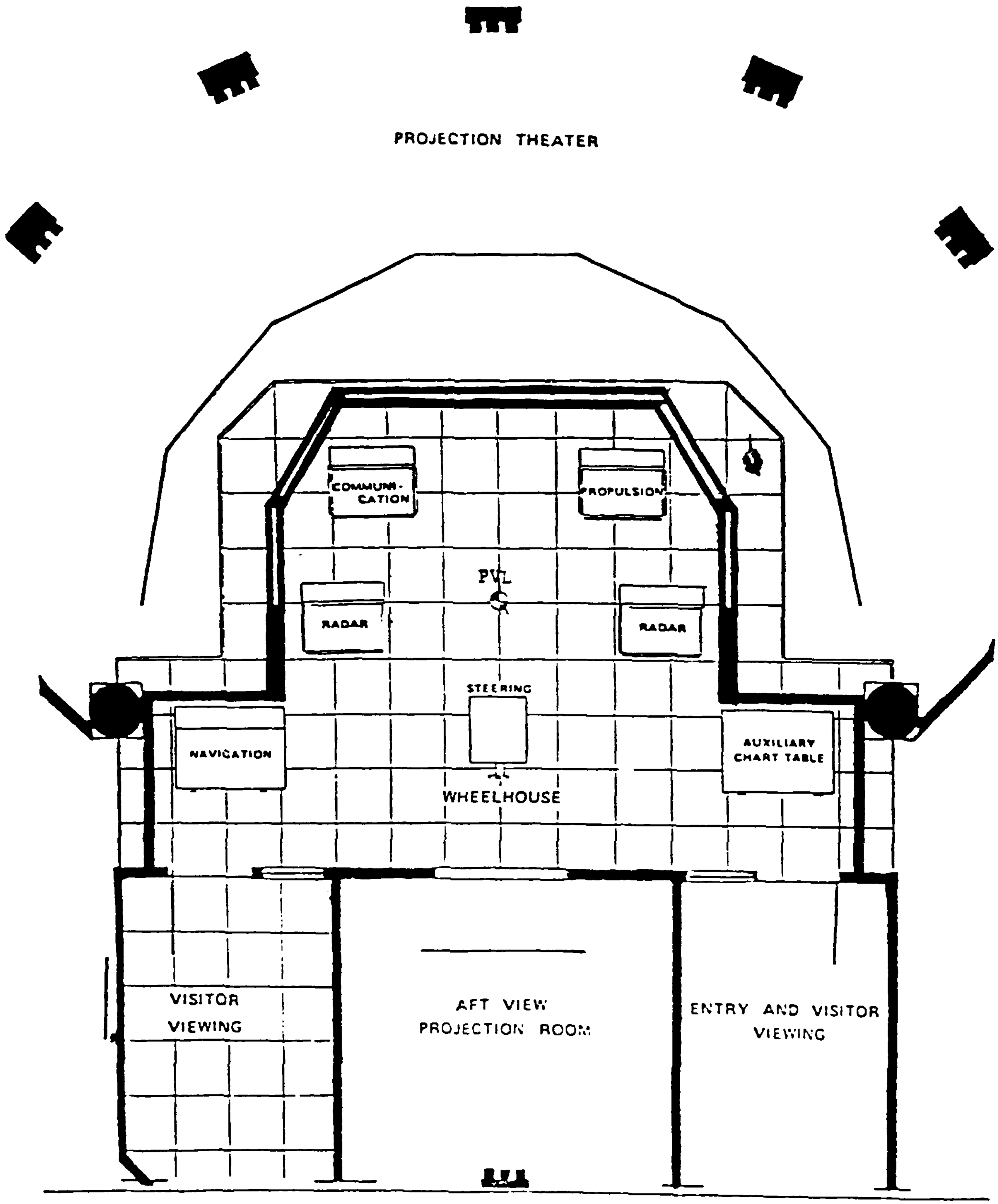


Figure A-1: Bridge Simulator Components



NOTE: PVL - Preferred Viewing Location

Figure A-2: Wheelhouse Arrangement - Plan View

result of control actions, for example, readings of the speed log, RPM and rudder angle indicators.

a. Steering Stand - includes rudder order, rudder angle (position) indicator, ship's wheel, steering mode selector, (manual, gyro and NFU modes of steering), gyro steering controls, gyrocompass repeater, and yaw rate indictor.

b. Propulsion Controls - includes engine orders telegraphs, propeller shaft RPM indicators, propeller pitch indicators and handle control units for twin or single screw operation.

c. Bow Thruster Control - direction and thrust magnitude command, motor amperes indicator.

d. Anchor Control - simulates the operation of the anchor windlass and permits the deployment of a bow anchor during vessel maneuvers. A control selector and anchor chain indicator (displaying the number of shots deployed) is provided.

e. Speed Log - provides a digital readout of the vessel's forward or aft speed. A selector permits either over-the-ground or through-the-water speed readouts.

f. Fathometer - displays a digital readout of under keel clearance in either feet or fathoms dependent upon selector position.

g. Gyrocompass Repeater Stand - a floor mounted pedestal fitted with a pelorus ring situated in the center of the wheelhouse for the purpose of taking visual bearings to objects in the visual scene.

h. Radio Direction Finder - an RDF unit with selector switch for obtaining radio bearings from up to four predesigned radio beacons.

i. LORAN C Receiver - displays a digital readout of latitude and longitude.

j. Bridge Clock - two digital clocks, one for a forward bridge console and the other at the navigation station. They are automatically set and will run with the simulation exercise.

k. Communication Equipment - a multi-channel VHF radio telephone transceiver, two intercom units (at the bridge console and navigation station) and ownship's whistle control. The intercom units are used for intra-ship communications such as with the forecastle, engine room, lookout, etc.

l. Overhead Mounted Indicators - includes indicators showing apparent wind speed and direction mounted over the forward windows, as well as repeaters of the rudder angle indicator and shaft RPM indicators.

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APPENDIX B

PILOT BRIEFING

INTRODUCTION

The experiment is designed to investigate the contribution to the piloting process of the visual environment provided by nearby shoreline. Today, you will be asked to make a number of transits, each with the same 30k dwt tanker through the same channel. For each transit the nearby shoreline will change. The shorelines will vary in their distance from the channel, their relative bearing from the ship's head at the turn, and the density of objects on the shore. Two scenarios will have only buoys, no shoreline, and one will be run at night.

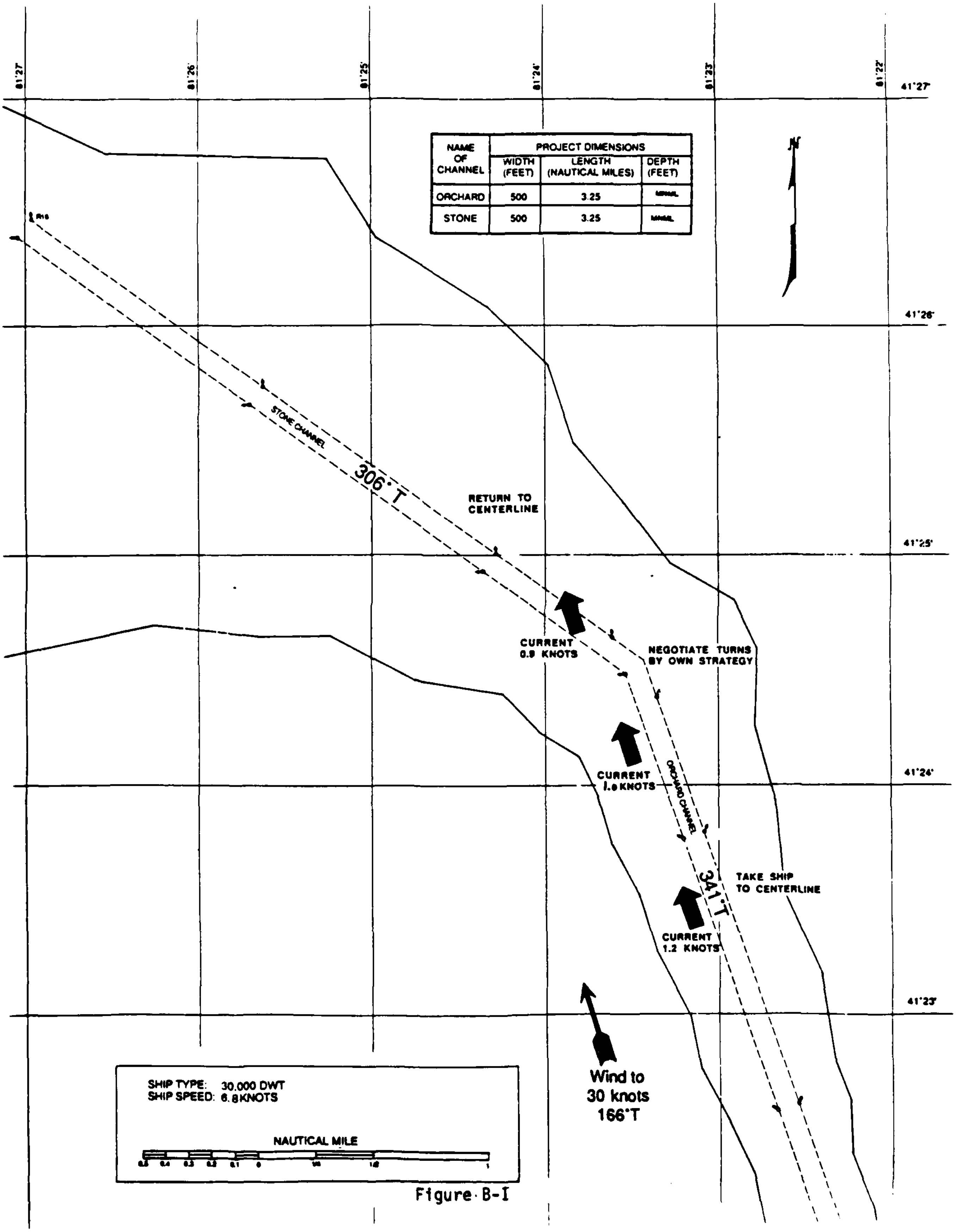
The briefing will be followed by a familiarization run that will give you the opportunity to familiarize yourself with the bridge, the ship's maneuvering characteristics, the channel, and the wind and current. Then, there will be 9 experimental transits of approximately 35 minutes each. You will be asked to comment on each transit. Please feel free to ask questions or comment at any time.

CHANNEL, CURRENT, AND WIND

The channel is illustrated in Figure B-1. It is 500 feet wide with a single 35 degree turn to the left. There are no bank effects. The channel's depth will provide sufficient underkeel clearance to the ship.

The current generally follows the course of the first leg of the channel. Its velocity is 1.4 knots at the start of the channel, then decreases throughout the length. At the start of the second leg, at the turn pullout it will be on the ship's port quarter with a velocity of 0.9 knots. It gradually turns to follow the channel again and continues to decrease in velocity. (The current is the same in each scenario even though the shoreline changes.)

There is a wind gusting to 30 knots with an average direction of 166 degrees throughout the scenario.



NAME OF CHANNEL	PROJECT DIMENSIONS		
	WIDTH (FEET)	LENGTH (NAUTICAL MILES)	DEPTH (FEET)
ORCHARD	500	3.25	[illegible]
STONE	500	3.25	[illegible]

Figure B-I

SHIP PARTICULARS

The ship is a 30,000 dead weight ton (dwt) tanker, with a length of 595 feet, a beam of 84 feet, and a draft of 35 feet. The ship is fully loaded. It has a split house with a bridge 85 feet forward from the center of gravity and a height of eye above the water of 48 feet.

The EOT, RPM, speed equivalents are as follows:

EOT	RPM	SPEED (KTS)
DEAD SLOW AHEAD	11	1.7
SLOW AHEAD	22	3.4
HALF AHEAD	44	6.8
FULL AHEAD	88	13.6

The maneuvering characteristics follow as Figure B-2.

BRIDGE LAYOUT AND EQUIPMENT

The bridge is laid out like a typical merchant bridge. There will be a helmsman to receive your orders. You will operate the EOT. Please announce your changes.

Radar will be available only for the familiarization scenario. Since this is an evaluation of the visual environment, there will be no radar available for the experimental scenarios. There will be a gyrocompass repeater with bearing ring, a rudder angle indicator, RPM indicator, speed log and ships clock. The preferred viewing location is at the center gyro repeater.

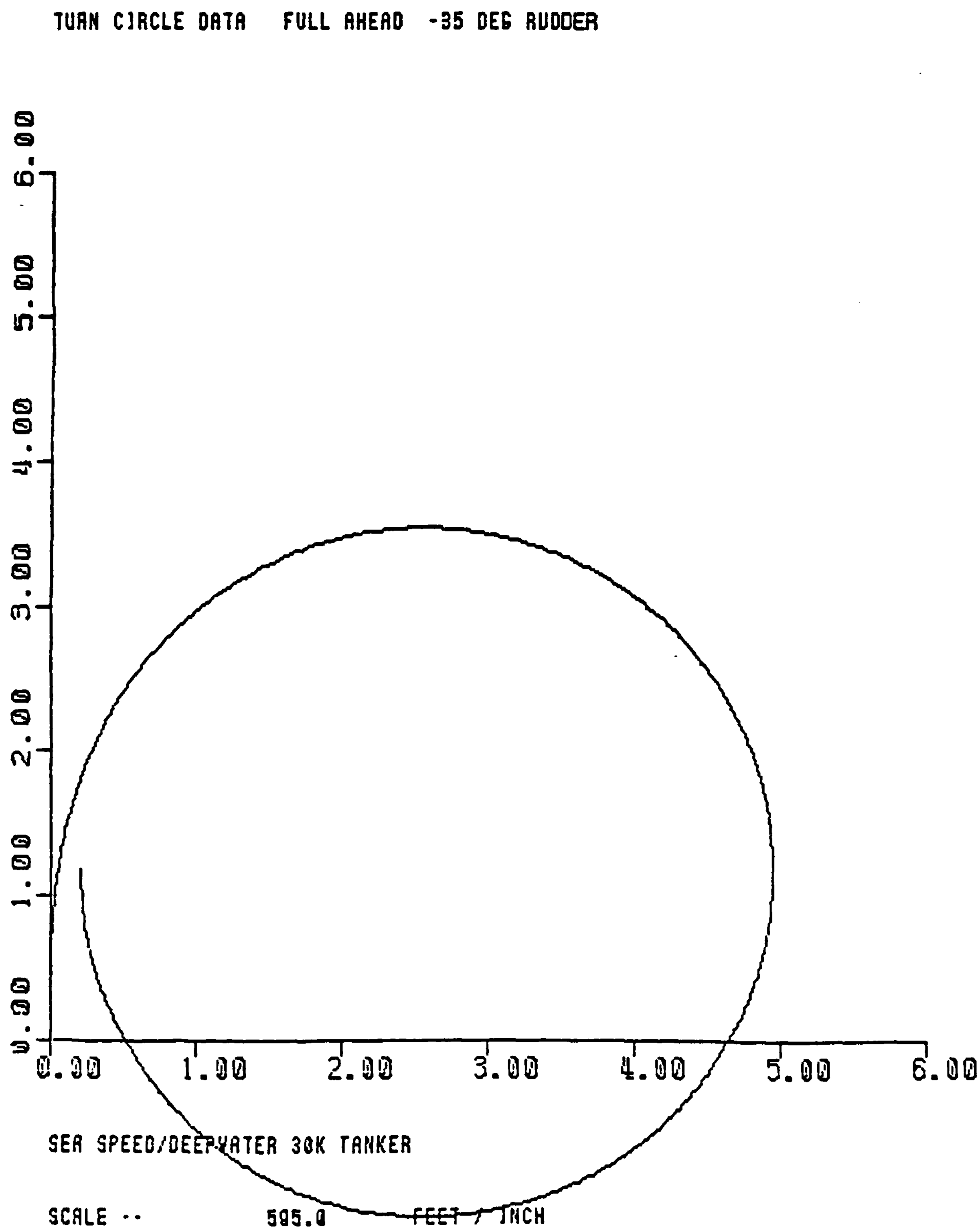

TURN CIRCLE DATA FULL AHEAD -35 DEG RUDDER
0.00
1.00
2.00
3.00
4.00
5.00
6.00
SEA SPEED/DEEPWATER 30K TANKER
SCALE -- 505.0 FEET / INCH

Figure B-2A

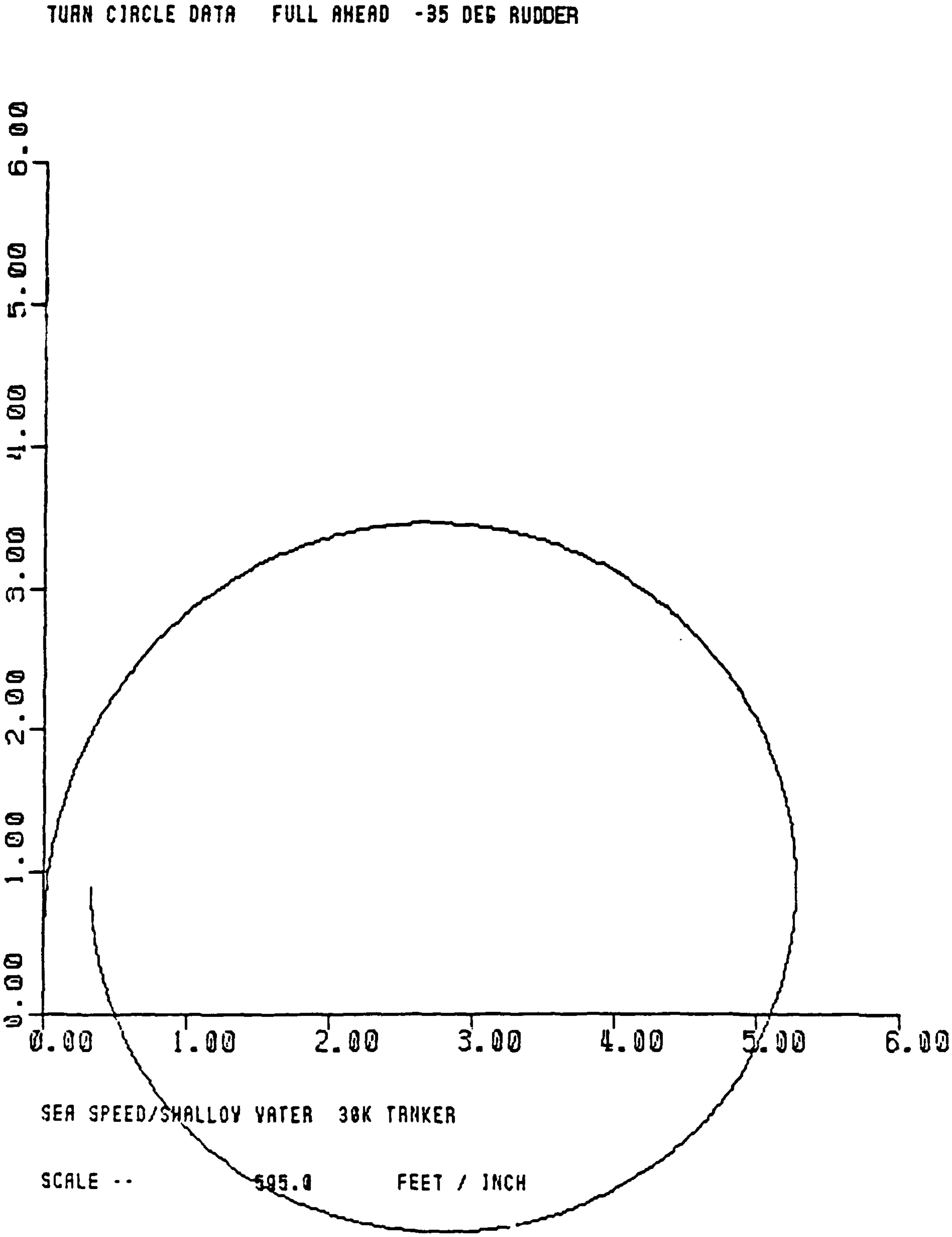

TURN CIRCLE DATA FULL AHEAD -35 DEG RUDDER
0.00
1.00
2.00
3.00
4.00
5.00
6.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
SEA SPEED/SHALLOW WATER 30K TANKER
SCALE -- 595.0 FEET / INCH

Figure B-2B

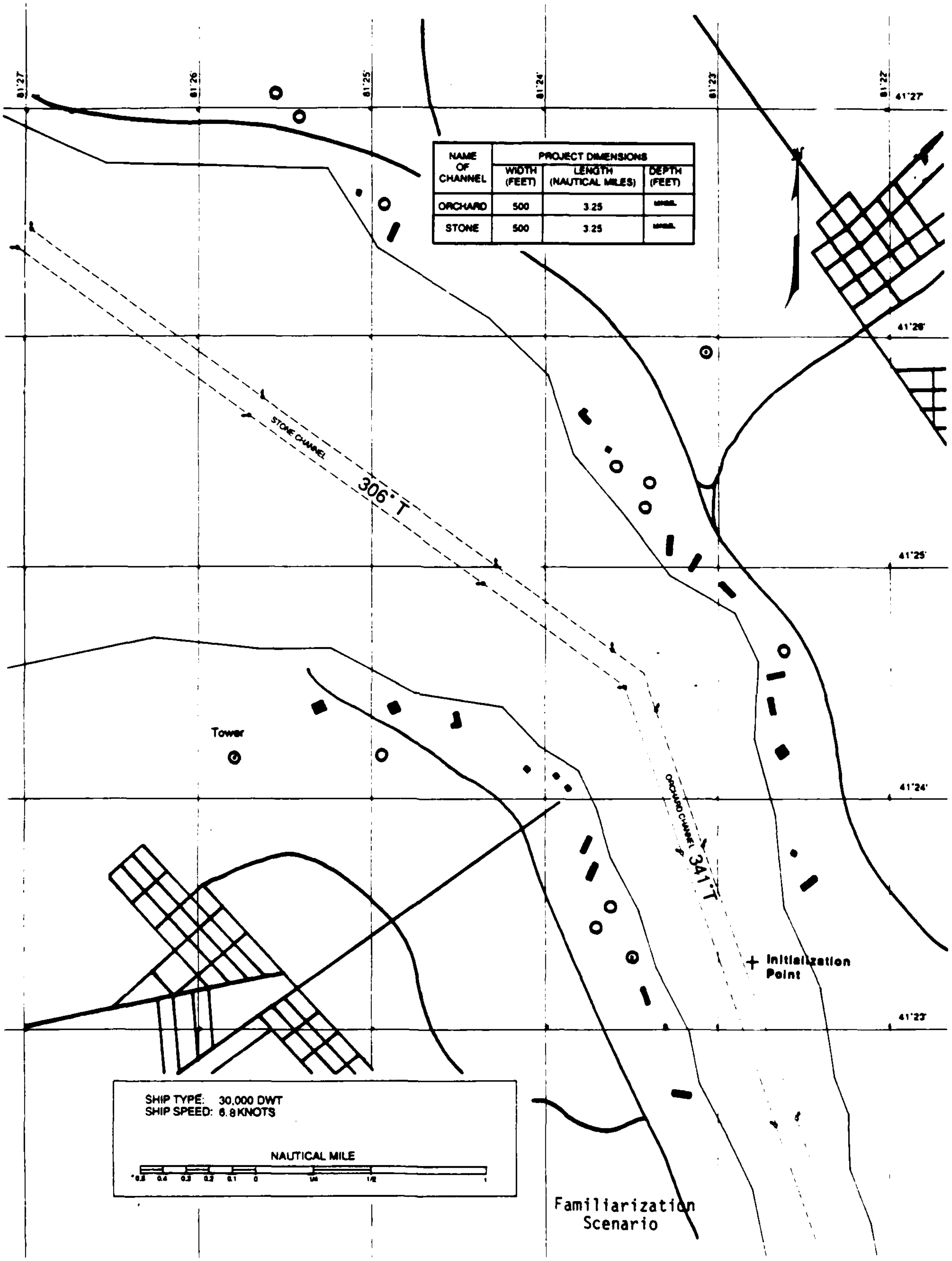
MANEUVERING INSTRUCTIONS FOR THE FAMILIARIZATION SCENARIO

For the familiarization scenario only, the scenario will start with the ship just outside the channel with a speed through the water of 6.8 knots. The current will generally follow the channel course with a velocity of approximately 1.2 at the start of the run. Please take the ship into the channel and to the centerline of the channel as quickly as you think prudent. Please stay as close to a strictly defined "centerline" as you think practical. You may leave the centerline when you think it is necessary to approach the turn. Negotiate the turn by your own technique. You may temporarily increase the RPM in the turn. Please return to the original 6.8 knots as soon as possible in the next leg. The current will be on the port quarter with a velocity of 0.9 knots at the pullout. In the second leg please return to the centerline as soon as practical. When you judge that the ship has recovered from the turn and your are satisfied with your understanding of the current, please ask the operator to end the scenario.

The instructions to maintain the slow transit speed and to stay on the centerline are meant to increase the difficulty of the maneuvers.

A chart for the familiarization scenario is attached. The ship's location at the beginning is indicated.

Note: Only this scenario will begin outside the channel. The approach and entry into the channel is meant to help familiarize you with the ship. Later scenarios will start inside the channel.



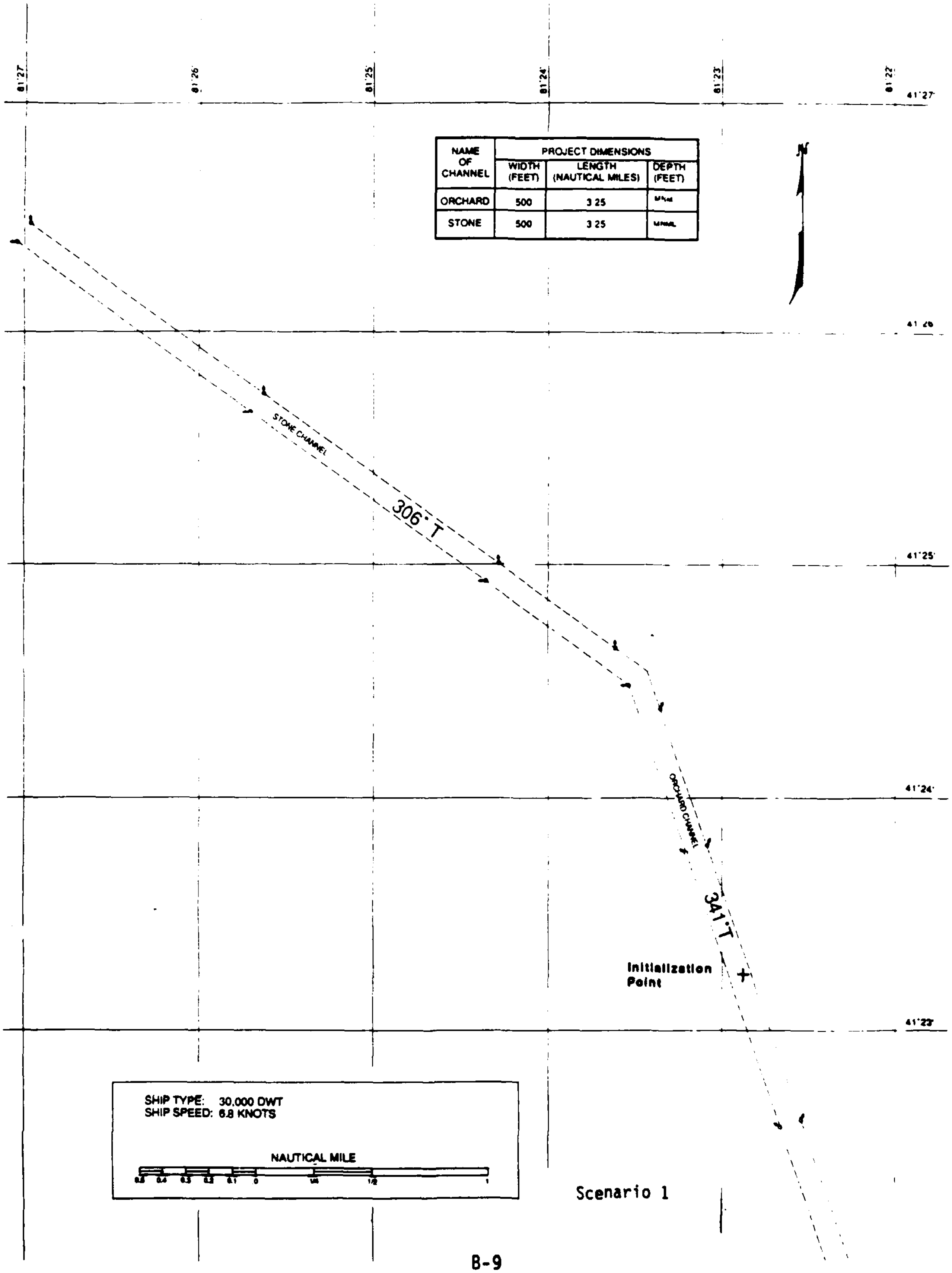
Familiarization Scenario

MANEUVERING INSTRUCTIONS FOR THE EXPERIMENTAL SCENARIOS

For all the remaining scenarios, the scenario will start with the ship approximately 1-1/3 nautical miles (nm) below the turn, one hundred feet to the right of the centerline. The current will be approximately 1.2 knots at the start of the run. The ship's speed will be 6.8 knots through the water.

Please take the ship to the centerline as quickly as you think prudent. Please stay as close to a strictly defined "centerline" as you think practical. You may leave the centerline when you think it is necessary to approach the turn. Negotiate the turn by your own technique. You may temporarily increase the RPM in the turn. Please return to the original 6.8 knots as soon as possible in the next leg. The current will be on the ship's port quarter with a velocity of 0.9 knots at the pullout. In the second leg please return to the centerline as soon as practical. Maintain the centerline until the end of the scenario.

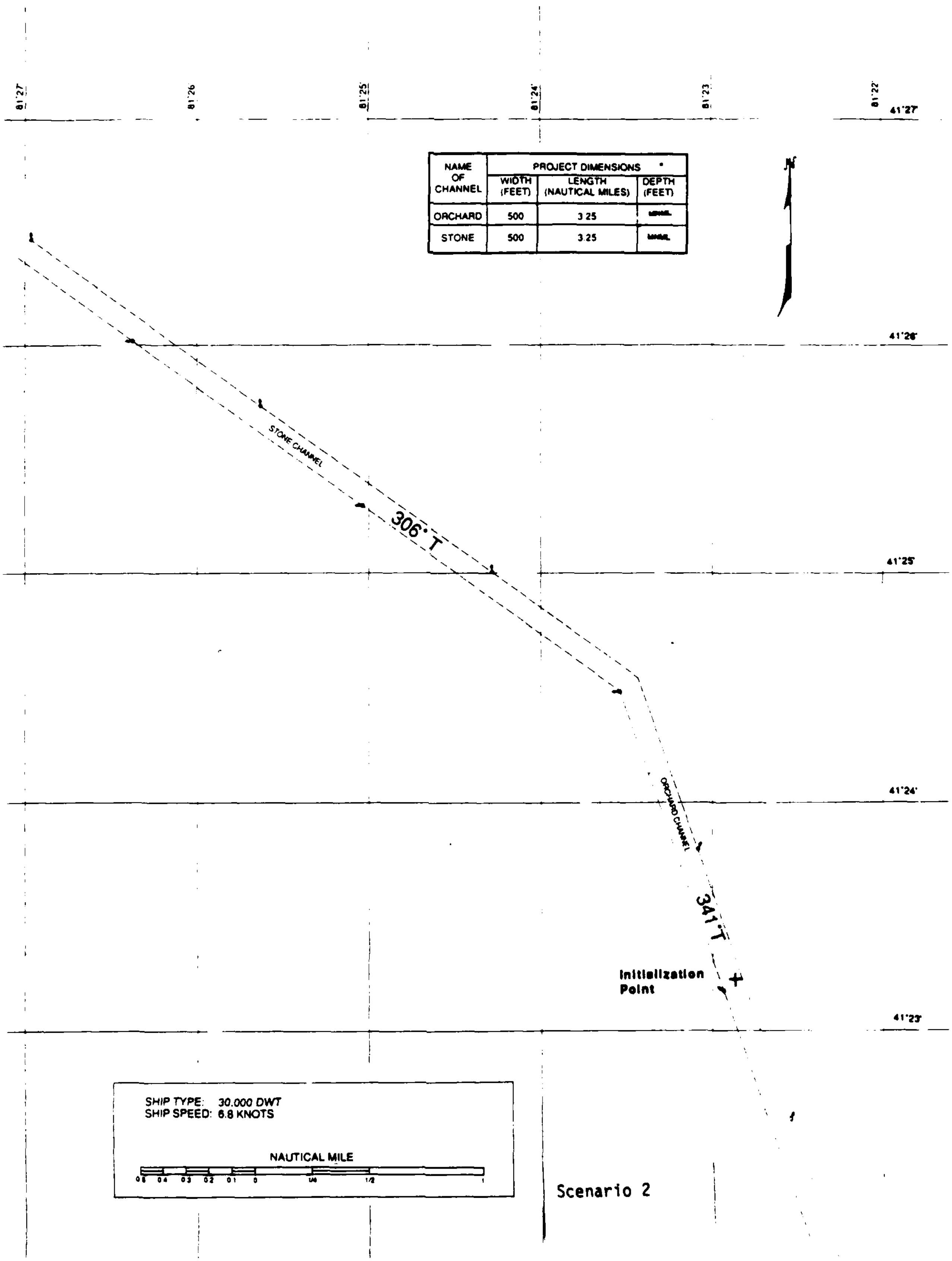
There are charts attached for each experimental scenario. The beginning and end of the transit are marked.



NAME OF CHANNEL	PROJECT DIMENSIONS		
	WIDTH (FEET)	LENGTH (NAUTICAL MILES)	DEPTH (FEET)
ORCHARD	500	3 25	[illegible]
STONE	500	3 25	[illegible]

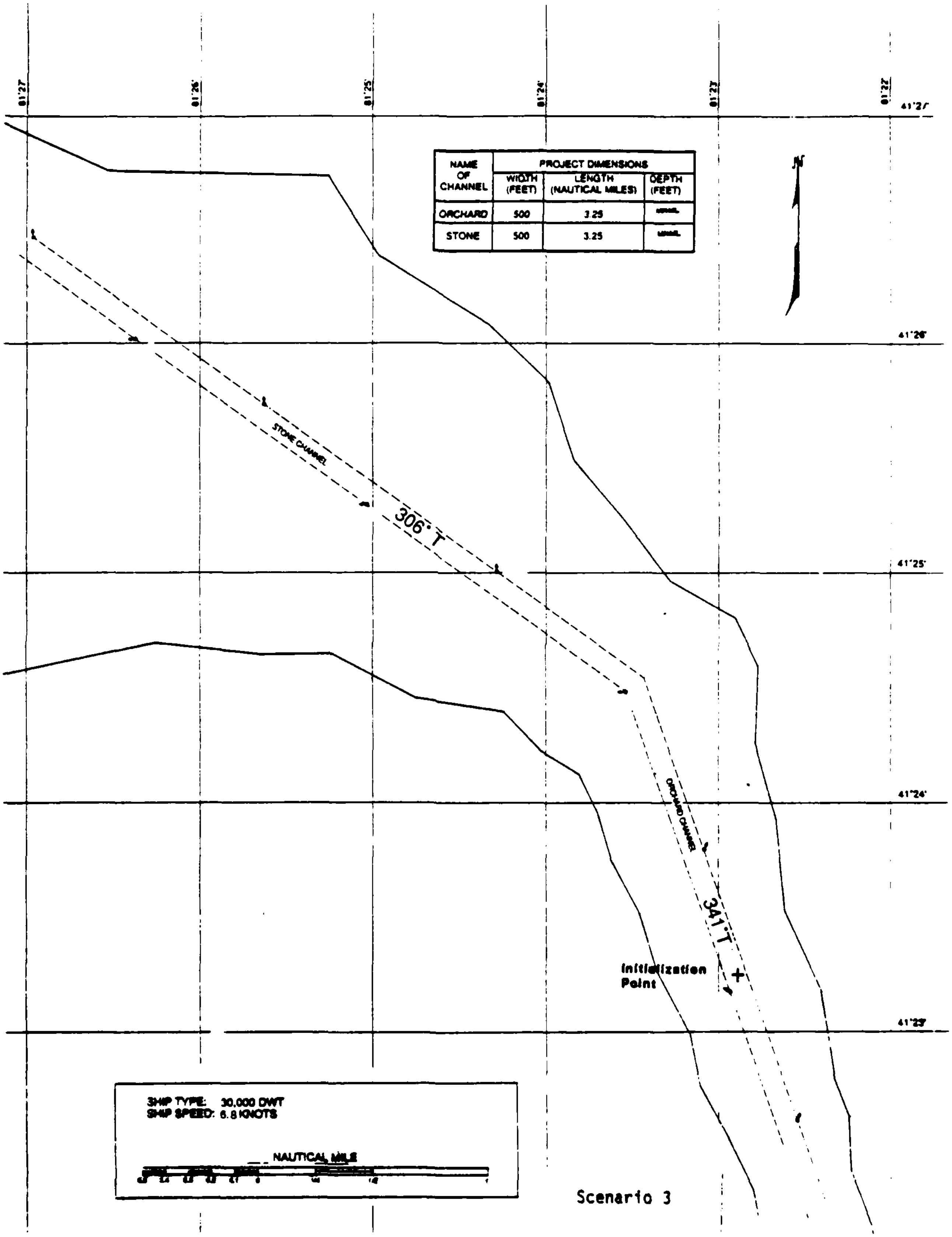
SHIP TYPE: 30,000 DWT
SHIP SPEED: 6.8 KNOTS

Scenario 1



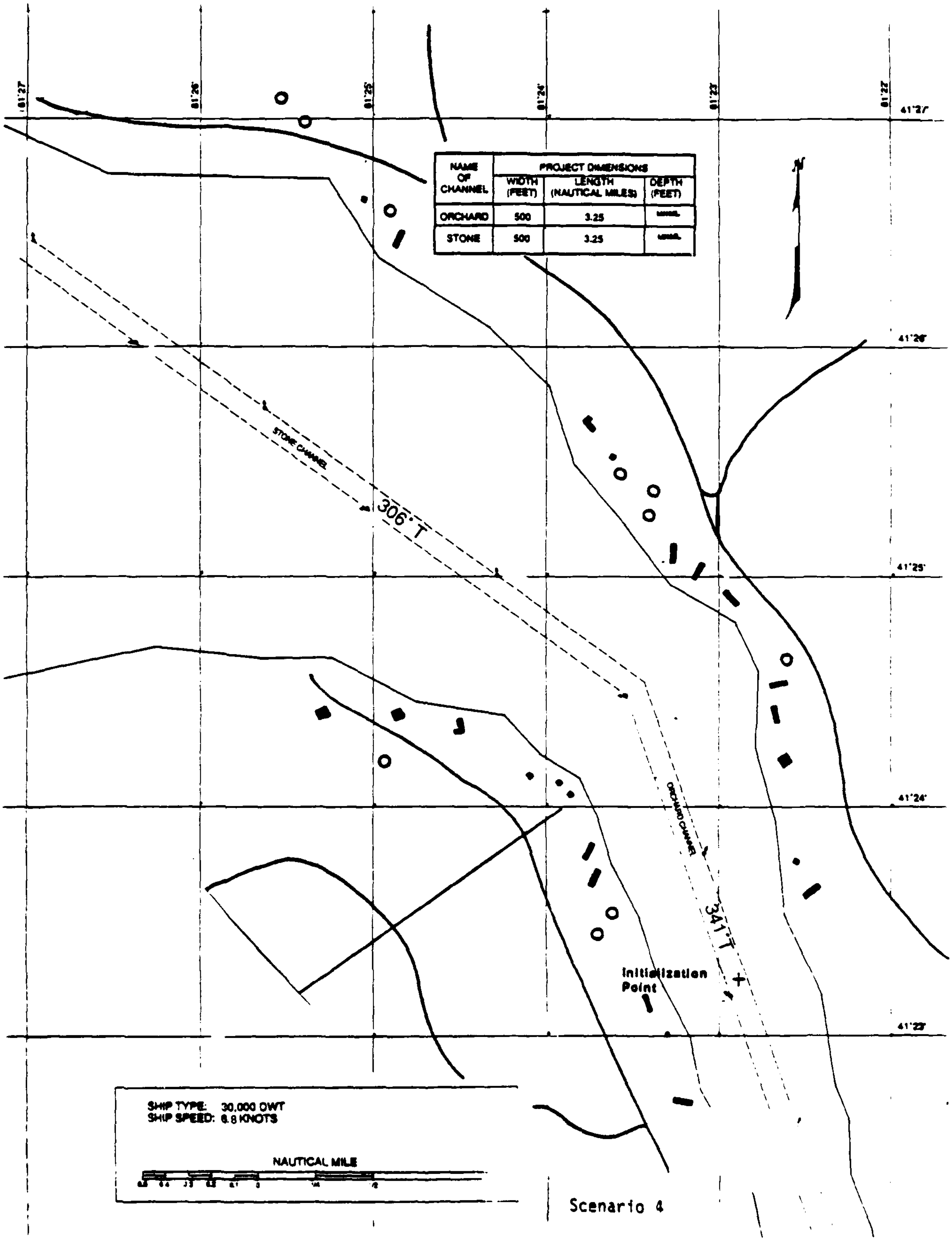
NAME OF CHANNEL	PROJECT DIMENSIONS *		
	WIDTH (FEET)	LENGTH (NAUTICAL MILES)	DEPTH (FEET)
ORCHARD	500	3.25	[illegible]
STONE	500	3.25	[illegible]

Scenario 2



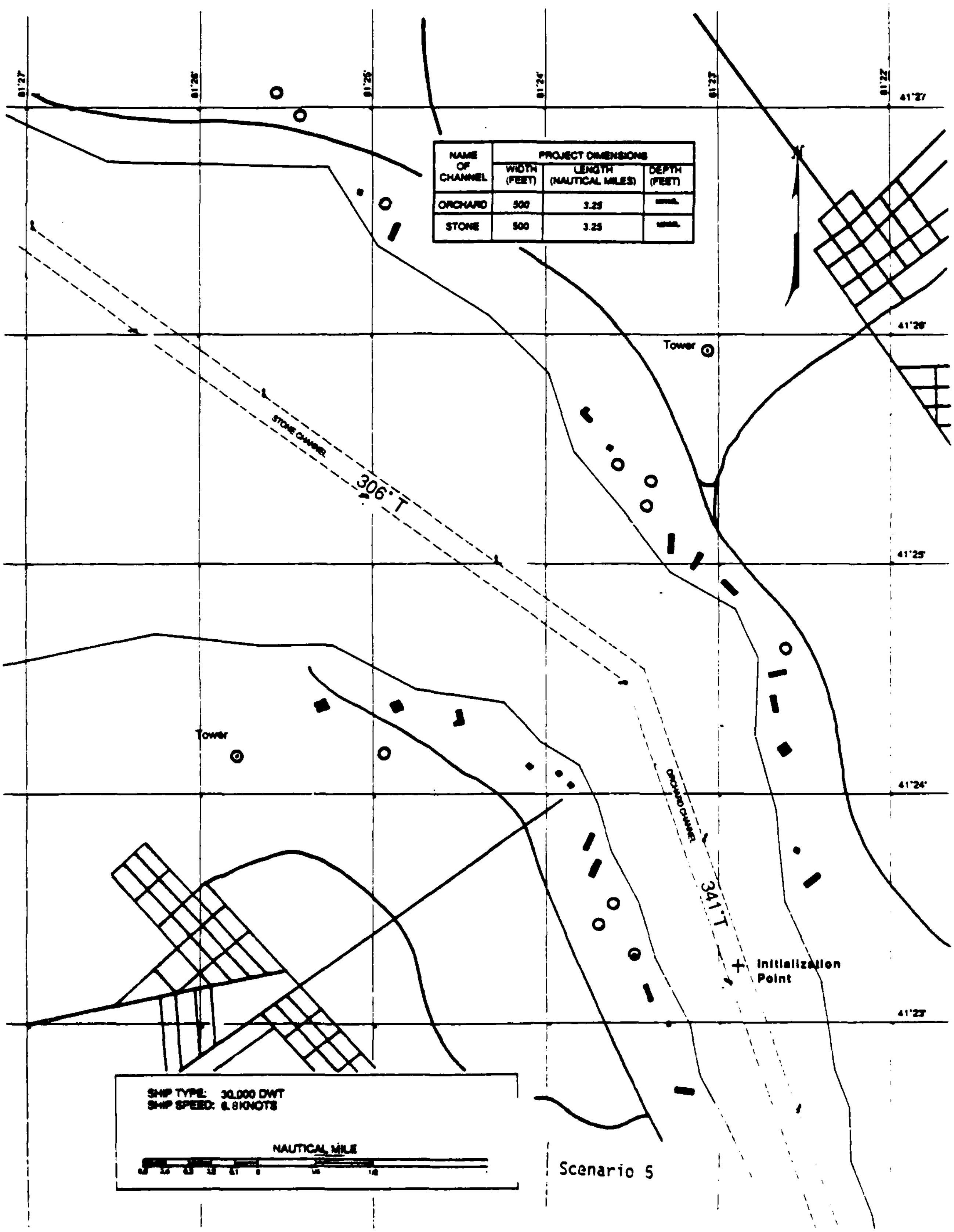
NAME OF CHANNEL	PROJECT DIMENSIONS		
	WIDTH (FEET)	LENGTH (NAUTICAL MILES)	DEPTH (FEET)
ORCHARD	500	3.25	[illegible]
STONE	500	3.25	[illegible]

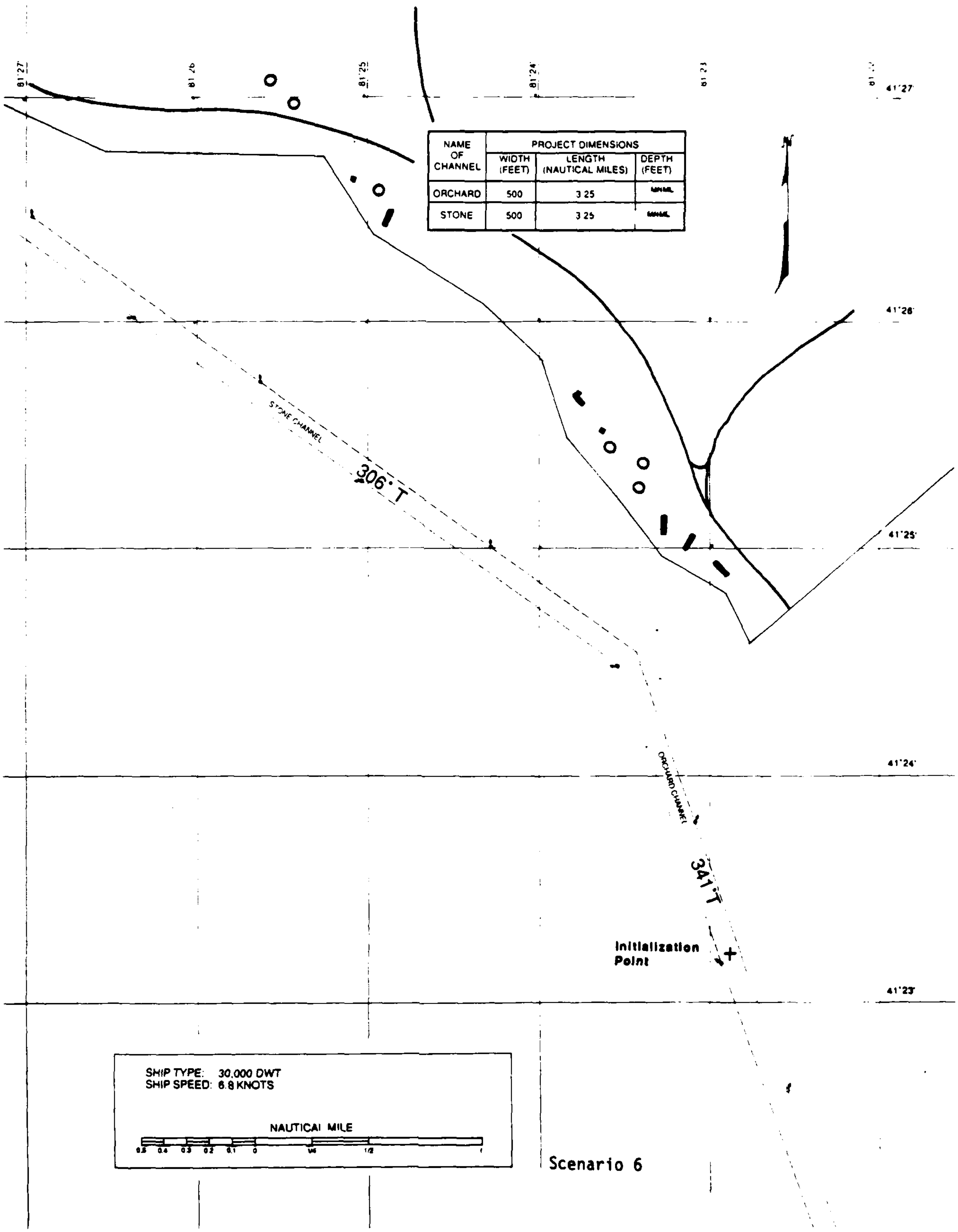
Scenario 3



NAME OF CHANNEL	PROJECT DIMENSIONS		
	WIDTH (FEET)	LENGTH (NAUTICAL MILES)	DEPTH (FEET)
ORCHARD	500	3.25	[illegible]
STONE	500	3.25	[illegible]

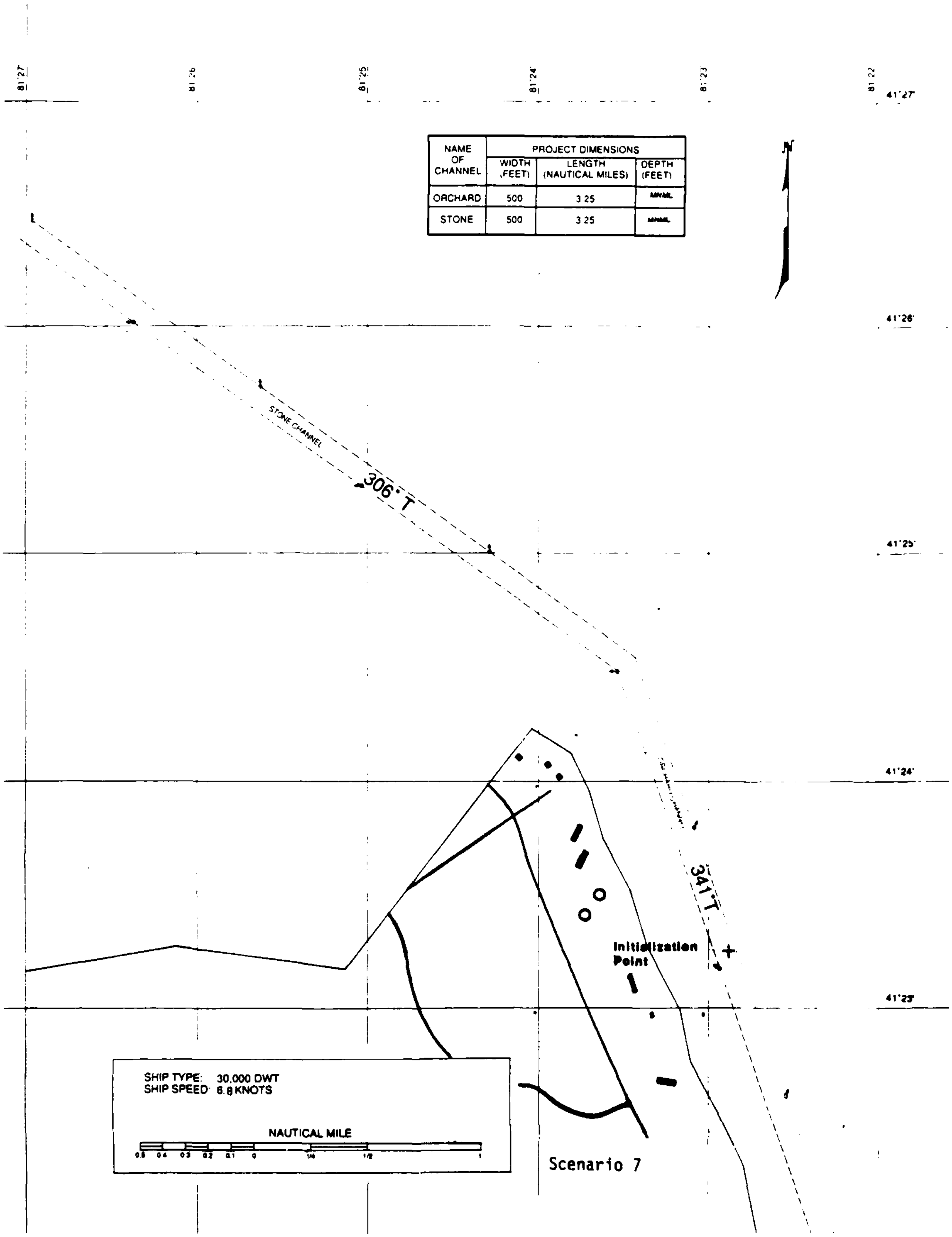
Scenario 4


81°27'
81°26'
81°25'
81°24'
81°23'
81°22'
41°27'
41°26'
41°25'
41°24'
41°23'
NAME OF CHANNEL
PROJECT DIMENSIONS
WIDTH (FEET)
LENGTH (NAUTICAL MILES)
DEPTH (FEET)
ORCHARD
500
3.25
STONE
500
3.25
Tower
STONE CHANNEL
306° T
Tower
ORCHARD CHANNEL
341° T
Initialization Point
SHIP TYPE: 30,000 DWT
SHIP SPEED: 6.8 KNOTS
NAUTICAL MILE
Scenario 5



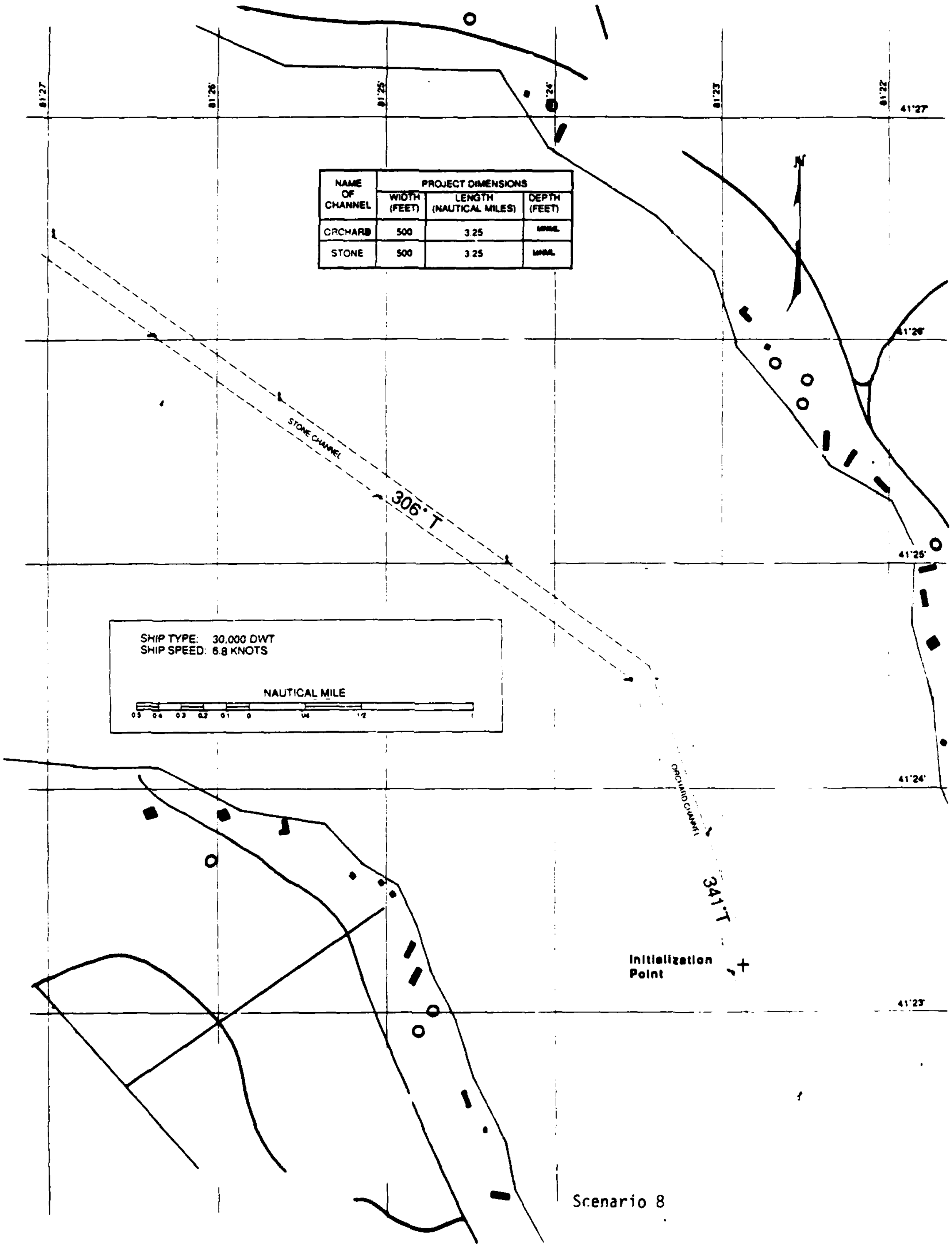
NAME OF CHANNEL	PROJECT DIMENSIONS		
	WIDTH (FEET)	LENGTH (NAUTICAL MILES)	DEPTH (FEET)
ORCHARD	500	3 25	[illegible]
STONE	500	3 25	[illegible]

Scenario 6



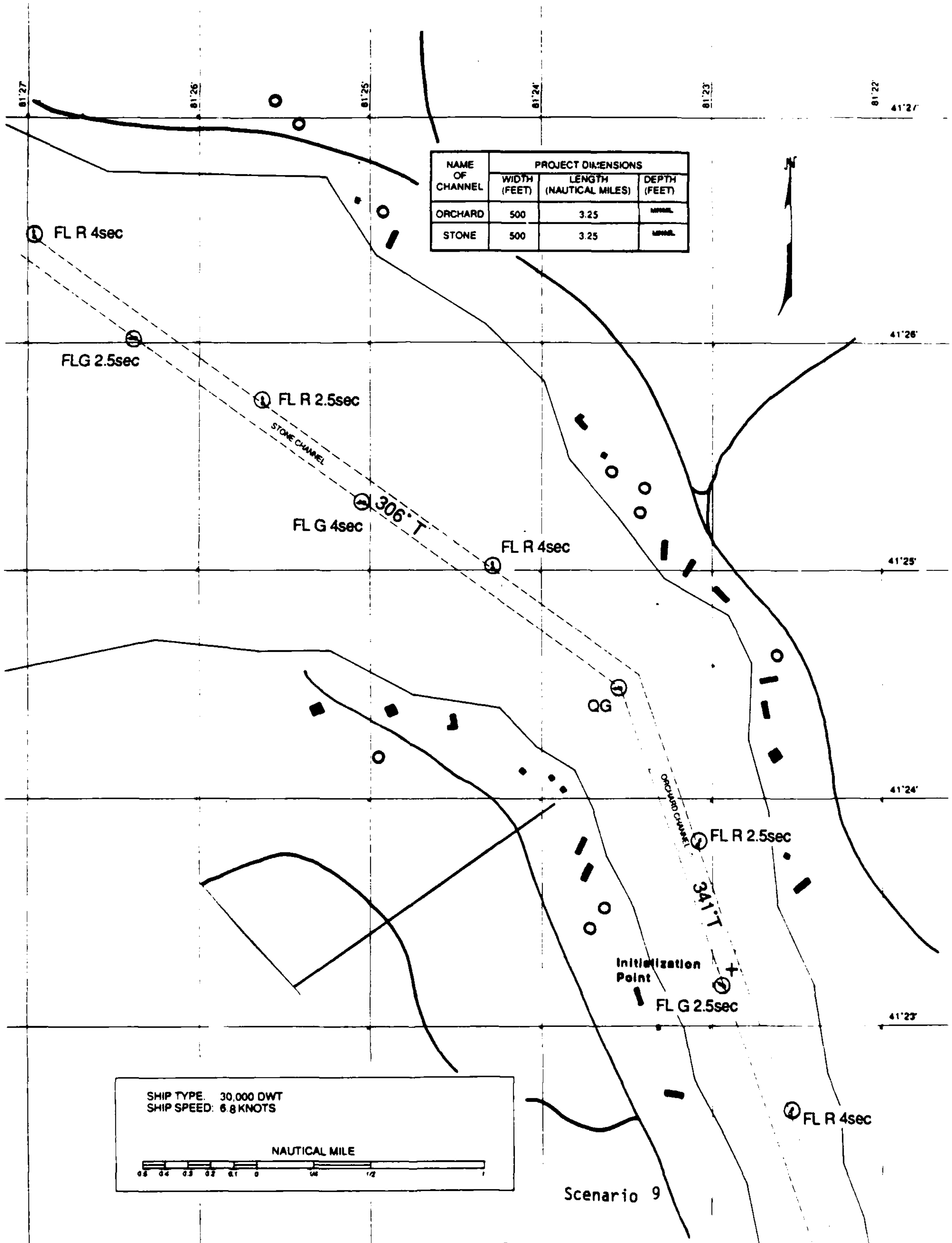
NAME OF CHANNEL	PROJECT DIMENSIONS		
	WIDTH (FEET)	LENGTH (NAUTICAL MILES)	DEPTH (FEET)
ORCHARD	500	3 25	[illegible]
STONE	500	3 25	[illegible]

Scenario 7



NAME OF CHANNEL	PROJECT DIMENSIONS		
	WIDTH (FEET)	LENGTH (NAUTICAL MILES)	DEPTH (FEET)
ORCHARD	500	3.25	[illegible]
STONE	500	3.25	[illegible]

Scenario 8



81°27'
81°26'
81°25'
81°24'
81°23'
81°22'
41°26'
41°25'
41°24'
41°23'
NAME OF CHANNEL
PROJECT DIMENSIONS
WIDTH (FEET)
LENGTH (NAUTICAL MILES)
DEPTH (FEET)
ORCHARD 500 3.25
STONE 500 3.25
FL R 4sec
FLG 2.5sec
FL R 2.5sec
STONE CHANNEL
306°T
FL G 4sec
FL R 4sec
QG
ORCHARD CHANNEL
FL R 2.5sec
341°T
Initialization Point
FL G 2.5sec
FL R 4sec
SHIP TYPE: 30,000 DWT
SHIP SPEED: 6.8 KNOTS
NAUTICAL MILE
Scenario 9

[BLANK]

APPENDIX C

PILOT DEBRIEFING

PILOT NAME ______________________________

General Questions. Please Comment.

1. Did the ship behave realistically as it was described?

   Was the bow realistic? the bridge wings? the bridge?

2. Did the wind and current behave realistically as described?

3. Was the familiarization scenario enough to familiarization you with the ship, current, wind, and channel?

   If not, what was needed?

4. How much did the centerline instructions and the slow speed contribute to the difficulty of the maneuvering needed for the transits?

5. Was the visual scene generally realistic?
   enough to help you in your transit?
   the buoys?
   the shoreline?
   objects?
   day and night differences?
   lights?

QUESTIONS FOR EACH SCENARIO

PILOT NAME______________________________

SCENARIO NUMBER______________________________

1a. Please describe the piloting techniques you used. How did you use the aids, shoreline, objects, during your transit?

1b. Please compare the piloting techniques you used to those in the familiarization scenario.

2a. How certain were you of the ship's position in this scenario?

1	2	3	4	5
Never certain of position				Always certain of position

2b. Please compare your certainty to that of the familiarization scenario.

3a. Where your helm orders influenced by the visual environment available in this scenario?

3b. How did the helm orders compare to these you gave in the familiarization scenario?

4a. What do you think the ship track looked like in this transit? Was it affected by the visual environment, the use you made of it, or the helm orders you gave?

4b. How do you think the ship tracks compare to those in the familiarization scenario?

5a. Was this a safe transit in your judgment? How safely could you have responded to traffic ships, emergencies, etc.?

5b. How did the transit safety compare to that of the familiarization run?

QUESTIONS FOR END OF THE DAY

PILOT NAME ______________________________

1. Please look over the chartlets for the scenarios you ran today. Can you sort them into groups that you judge to be similar in difficulty of maneuver, certainty of position, helm orders, ship tracks, and/or safety? You decide the number of groups that are needed.

   Can you describe the important differences between the groups for you?

2. Did you find the varied shoreline conditions realistic and representative of what you have experienced? If not, what would you have wanted to see included?

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APPENDIX D

COMBINED PLOTS: SCENARIOS 1-9

The combined plots which follow (described in Section 4.2) are a graphic representation of the experimental runs from which the performance data in Section 5 were selected. They are arranged in numerical order by scenario. These conditions are summarized in Table D-1, which is repeated from the text as a convenience for the reader.

The format of the plots is identical to that employed in Phase II. The axis for the abscissa is scaled so that one unit of alongtrack distance represents 476 feet (5/64 nm). At a speed of 6.8 knots, the data lines 476 feet apart represent samples approximately every 40 seconds. The combined plot shows the crosstrack mean and an envelope encompassing two standard deviations to either since, an area within which performance is expected to occur 95 percent of the time.

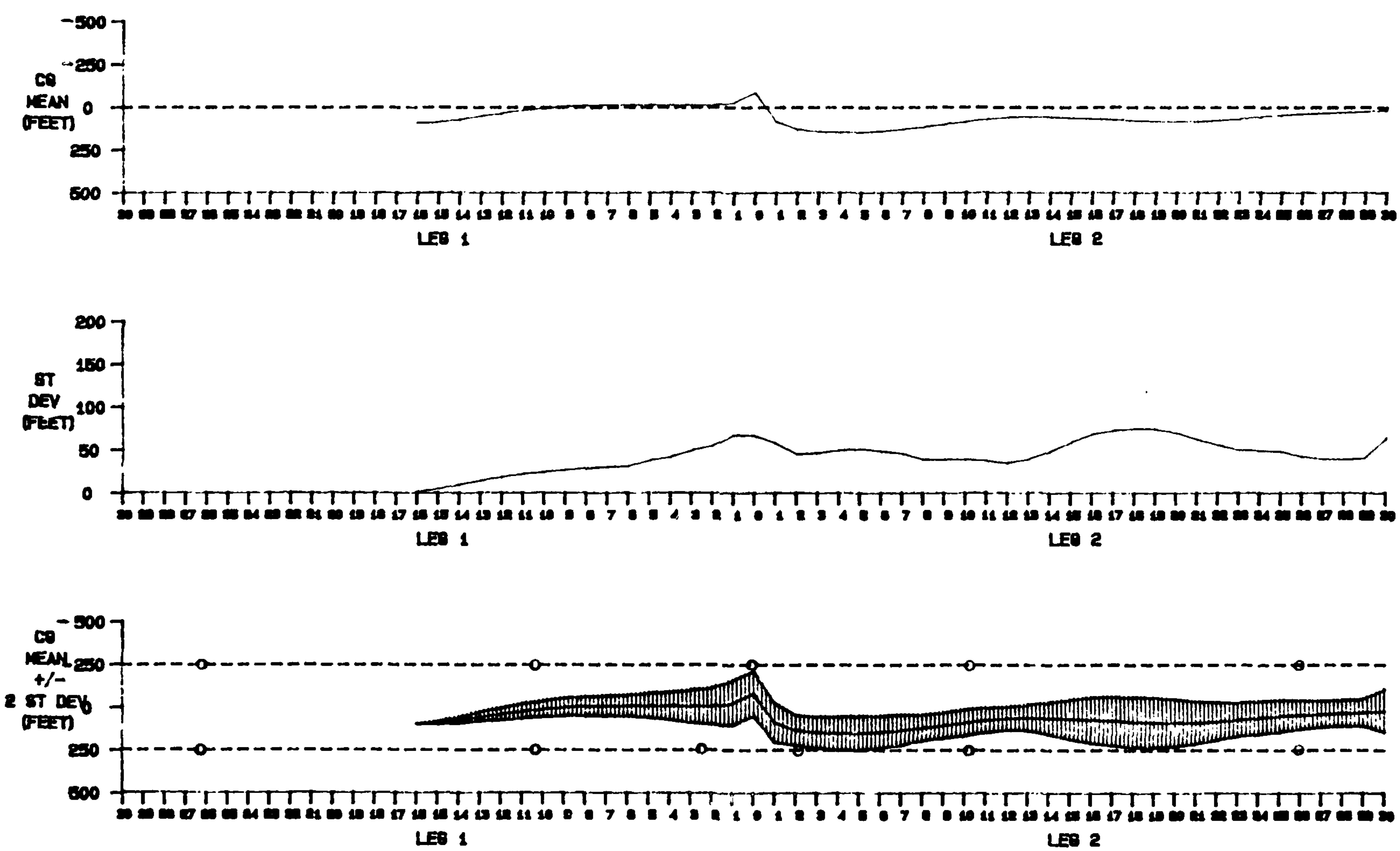
Buoys are positioned on the plots for purposes of illustration and may not appear in the exact location for the simulated scenario or chart diagrams.

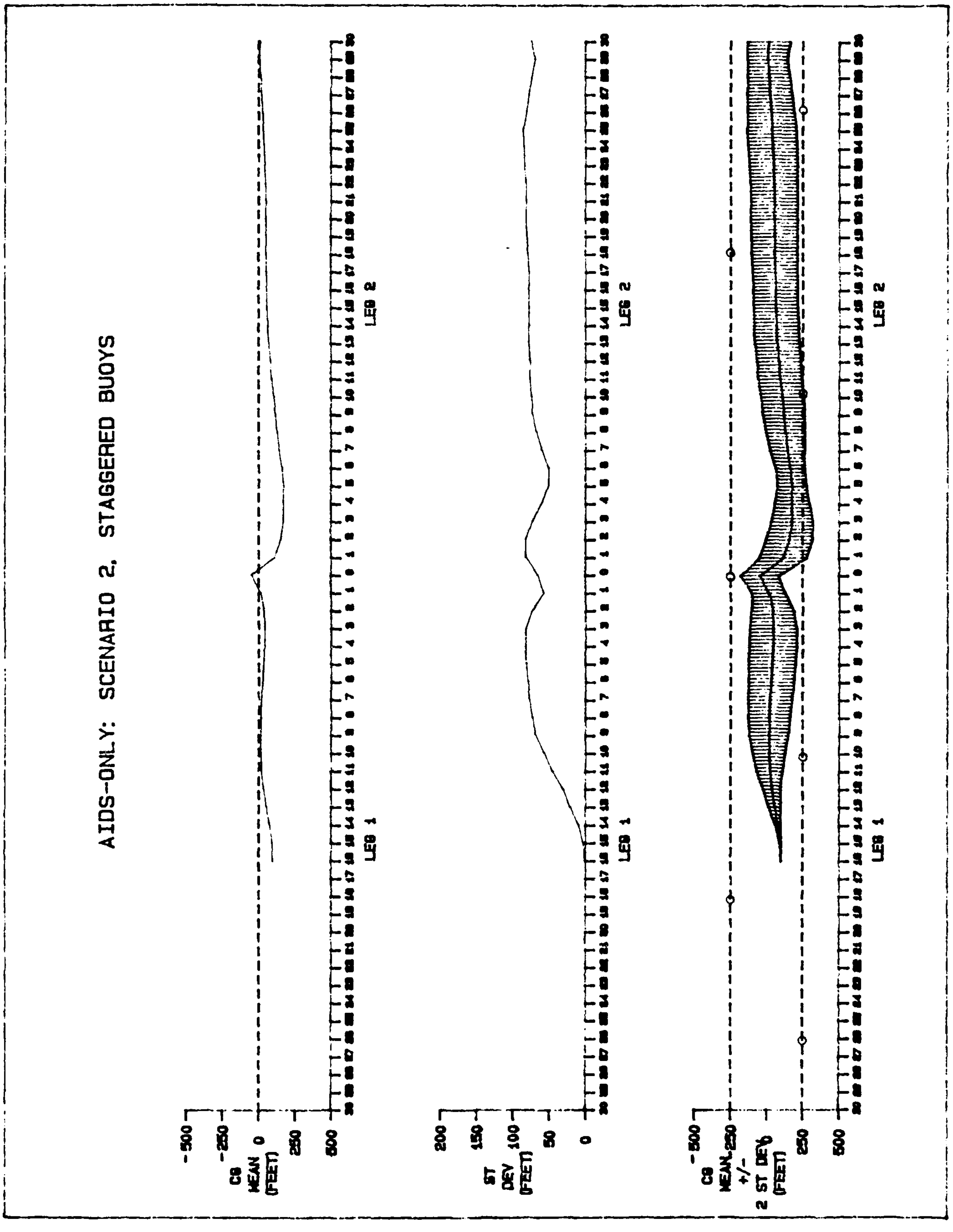
TABLE D-1. EXPERIMENTAL SCENARIOS

		Targets of Opportunity (TOOs) in Visual Surround			
Scenario	Aids	Density	Relative Bearing	Distance	Day/Night
Objective: Familiarization					
FAM	3-buoy turn, gated buoys	high, cultural objects	all around	within 1.5 nm*	day
Objective: Evaluation of Aid Arrangements					
1	3-buoy turn, gated buoys	none	none	none	day
2	1-buoy turn, staggered buoys	none	none	none	day
Objective: Evaluation of the Visual Environment: Density of Objects					
3	1-buoy turn, staggered buoys	low, landmass	all around	within 1.5 nm	day
A Representative Visual Environment					
4	1-buoy turn, staggered buoys	moderate, cultural objects	all around	within 1.5 nm	day
5	1-buoy turn, staggered buoys	high, cultural objects	all around	within 1.5 nm	day
Objective: Evaluation of Visual Environment: Relative Bearing of Objects					
6	1-buoy turn, staggered buoys	moderate, cultural objects	ahead setup, abeam pullout	within 1.5 nm	day
7	1-buoy turn staggered buoys	moderate, cultural objects	abeam setup, aft pullout	within 1.5 nm	day
Objective: Evaluation of Visual Environment: Distance					
8	1-buoy turn, staggered buoys	moderate, cultural objects	all around	within 2.5 nm	day
Objective: Evaluation of Visual Environment: Day/Night					
9	1-buoy turn, staggered buoys	moderate, cultural lights	all around	within 1.5 nm	night

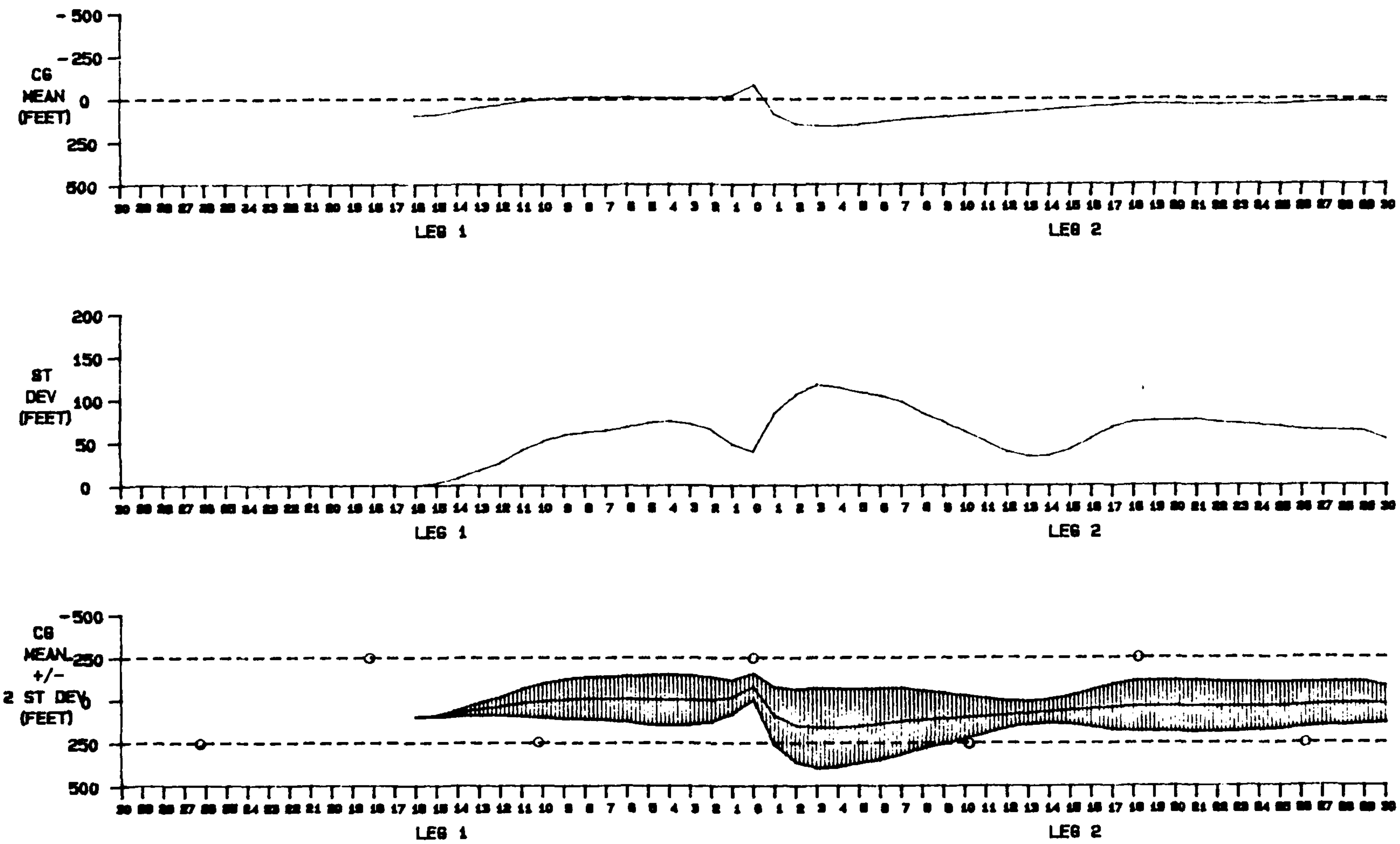
*nm is nautical mile

BASELINE: SCENARIO 1. GATED BUOYS

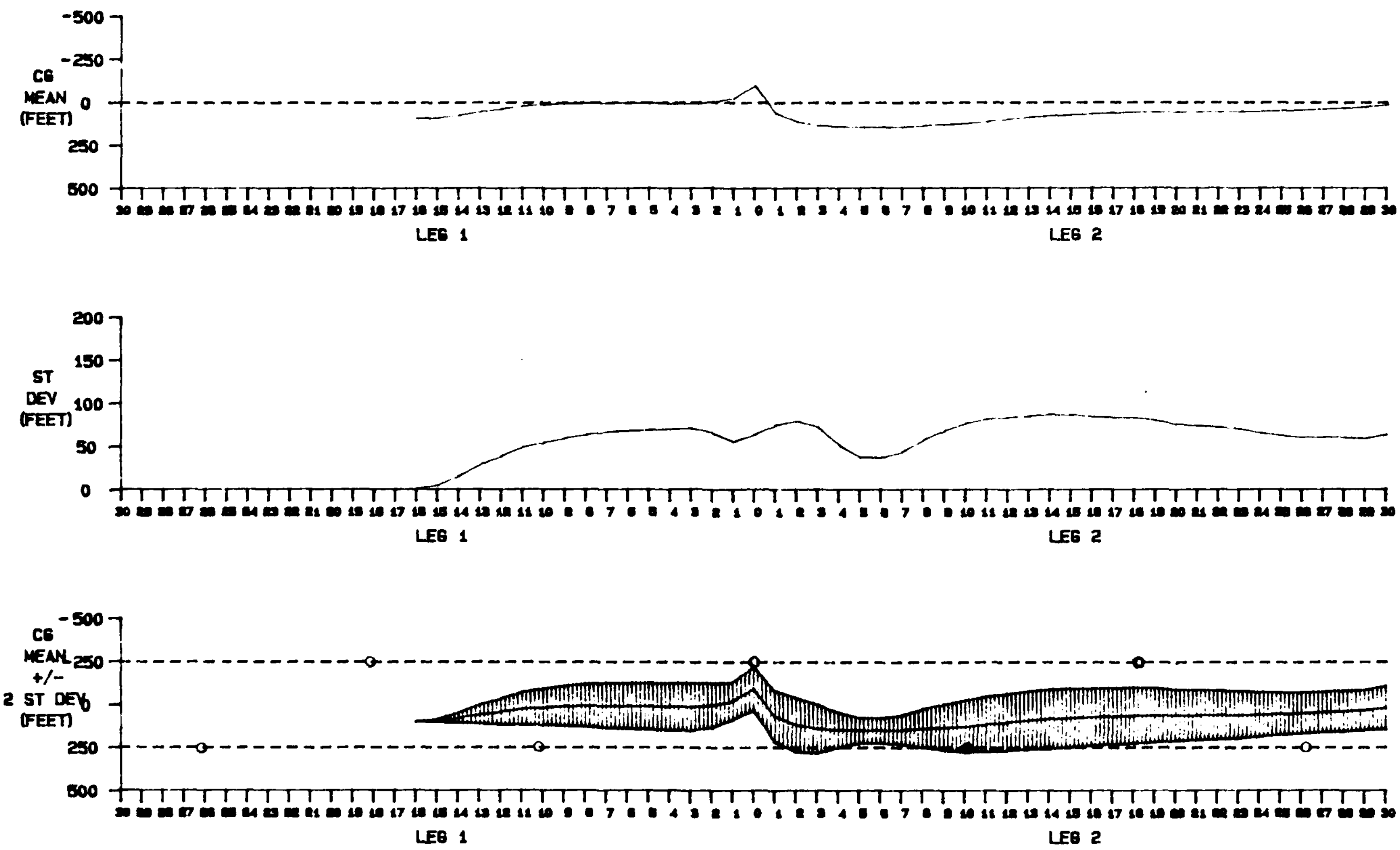


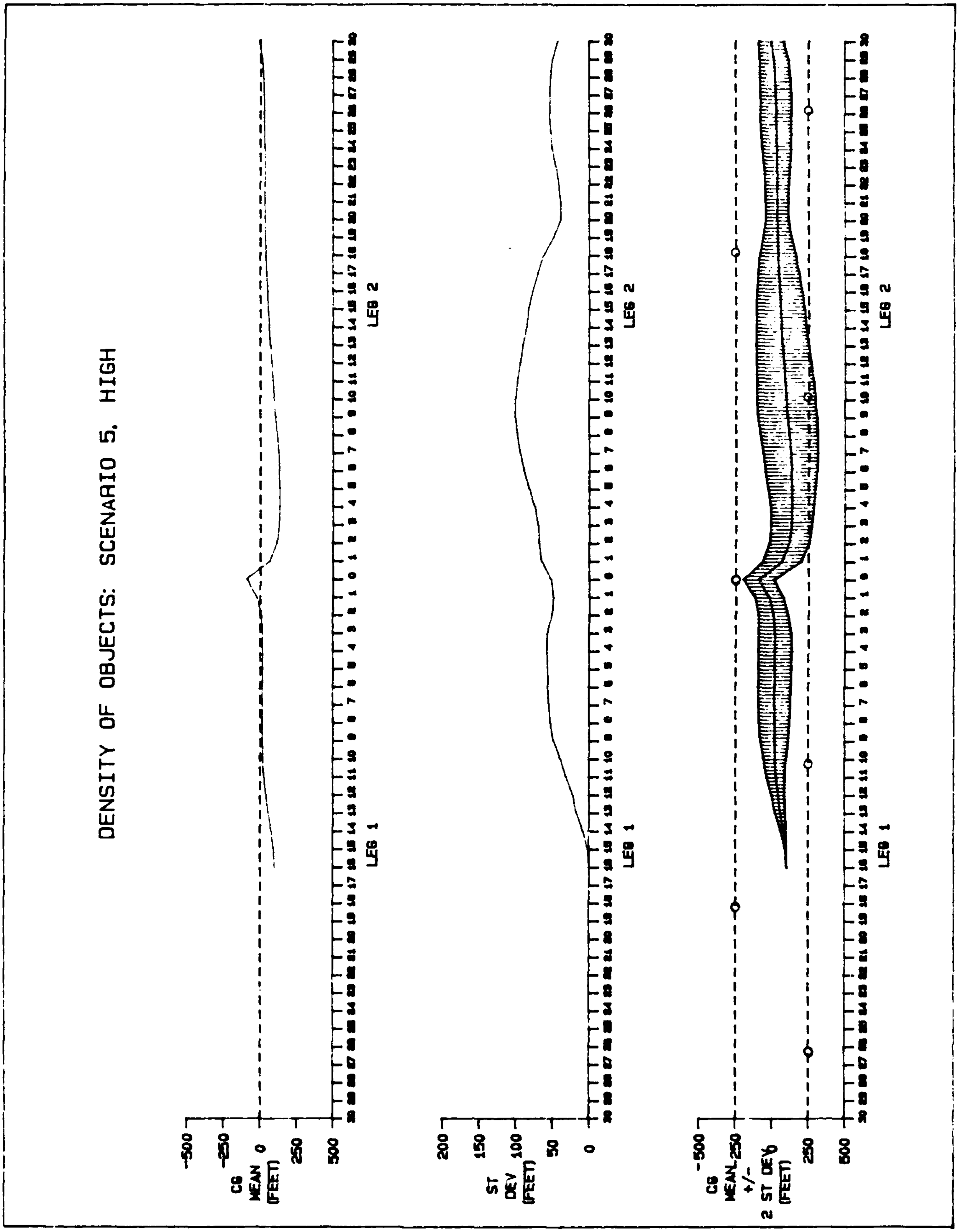

AIDS-ONLY: SCENARIO 2, STAGGERED BUOYS
CG MEAN (FEET)
-500
-250
0
250
500
ST DEV (FEET)
200
150
100
50
0
CG MEAN +/- 2 ST DEV (FEET)
-500
-250
250
500
LEG 1
LEG 2

DENSITY OF OBJECTS: SCENARIO 3, LAND ONLY



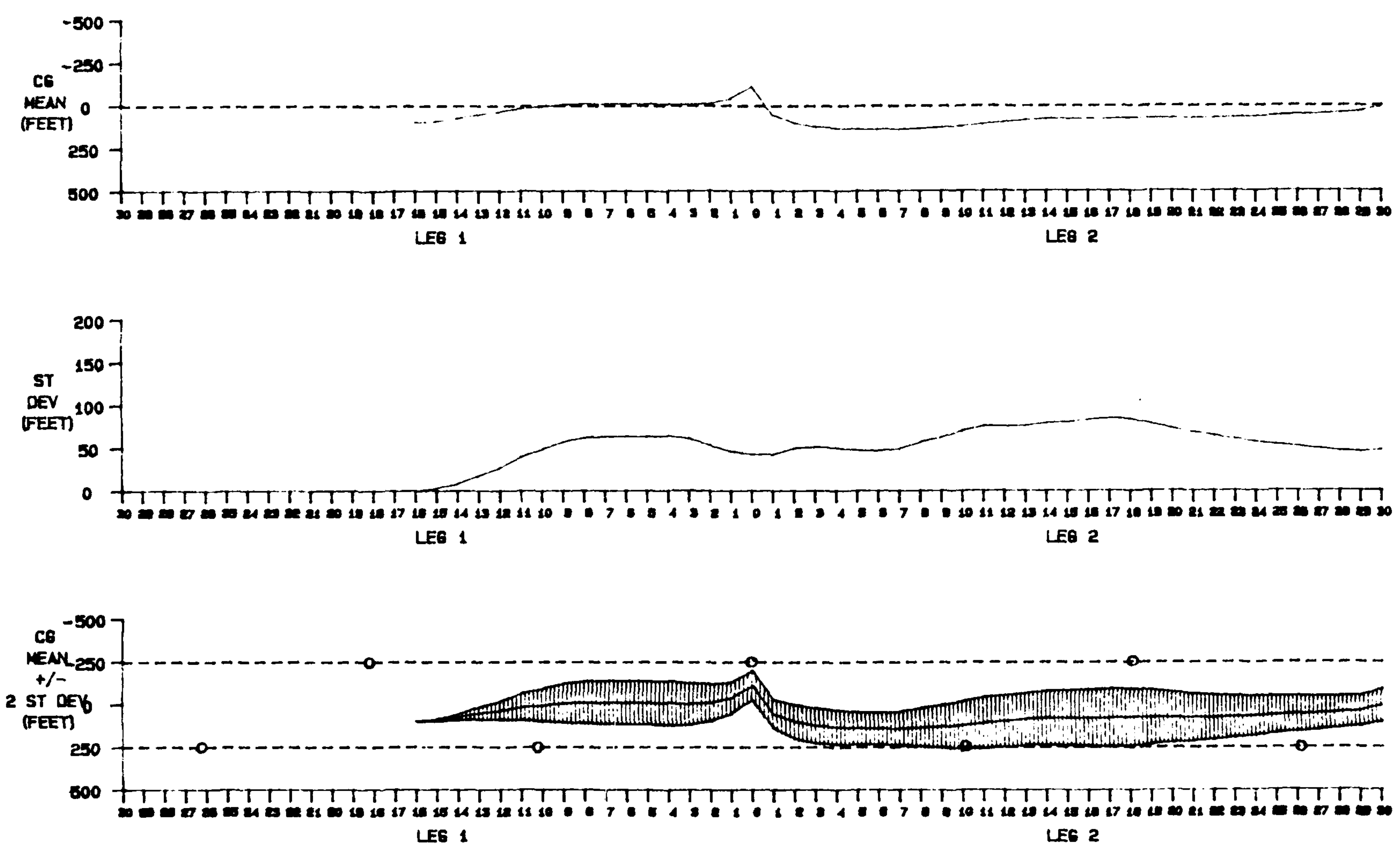
DENSITY OF OBJECTS: SCENARIO 4, MODERATE

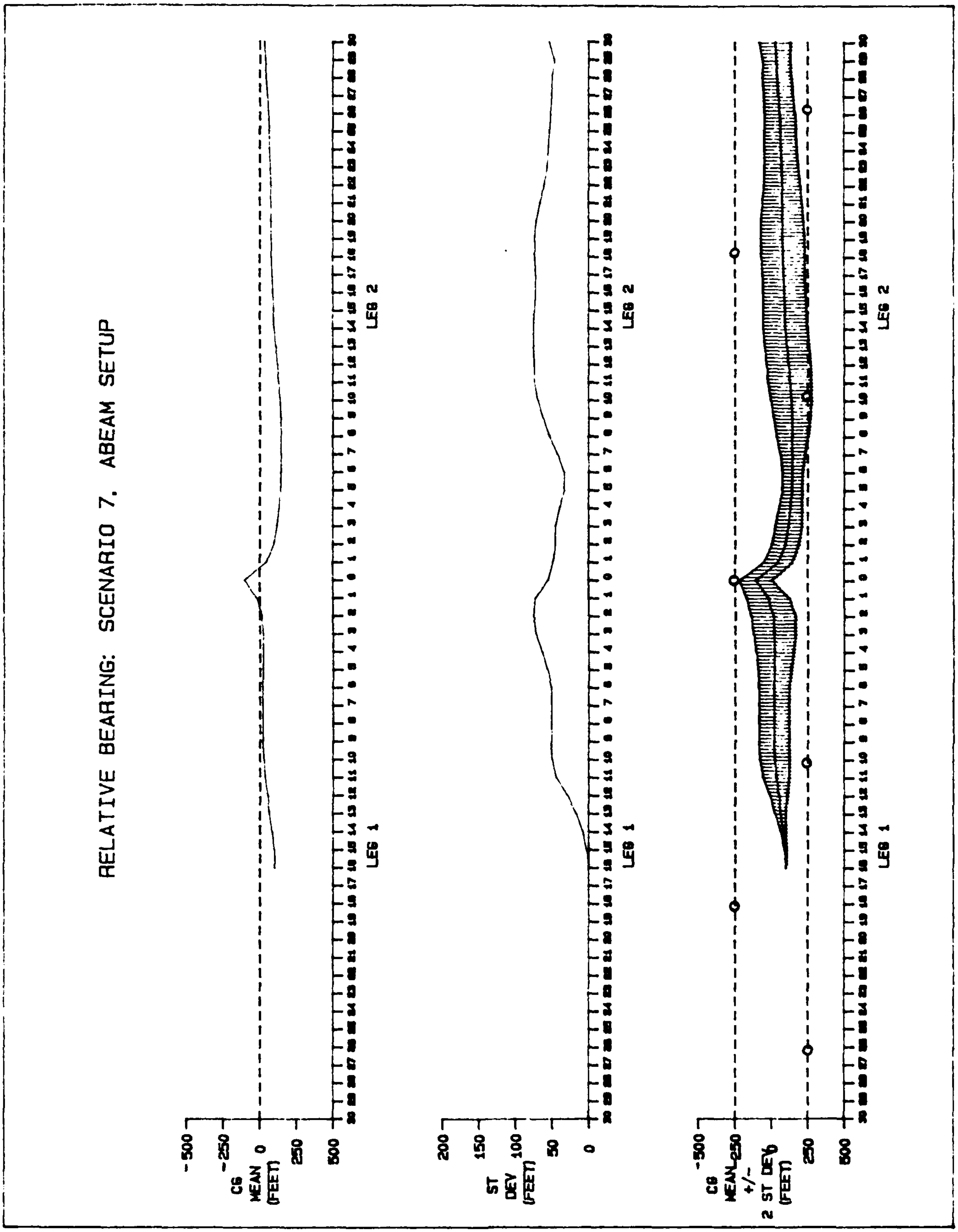




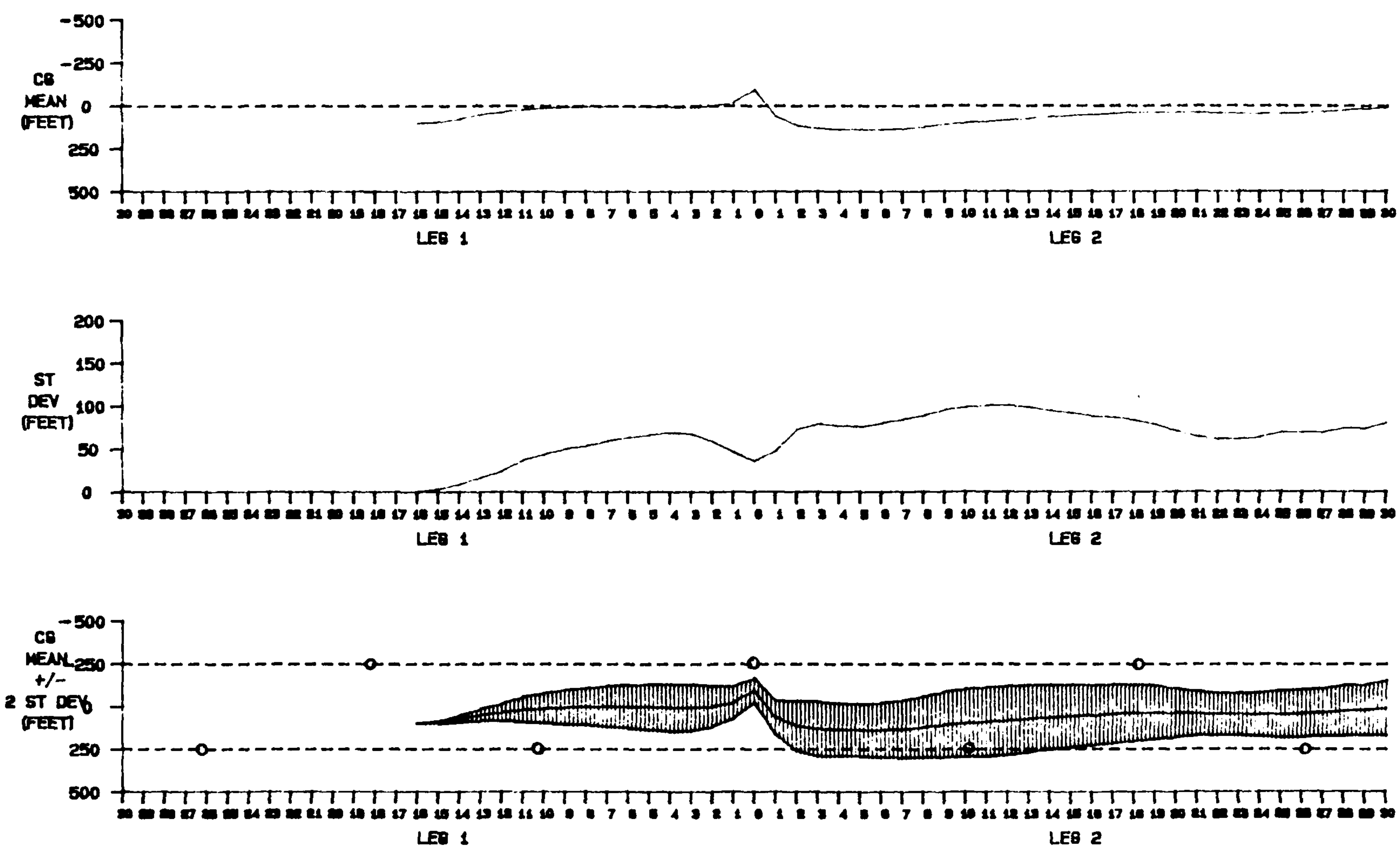
DENSITY OF OBJECTS: SCENARIO 5, HIGH
CG MEAN (FEET)
ST DEV (FEET)
CG MEAN +/- 2 ST DEV (FEET)
-500
-250
0
250
500
200
150
100
50
LEG 1
LEG 2

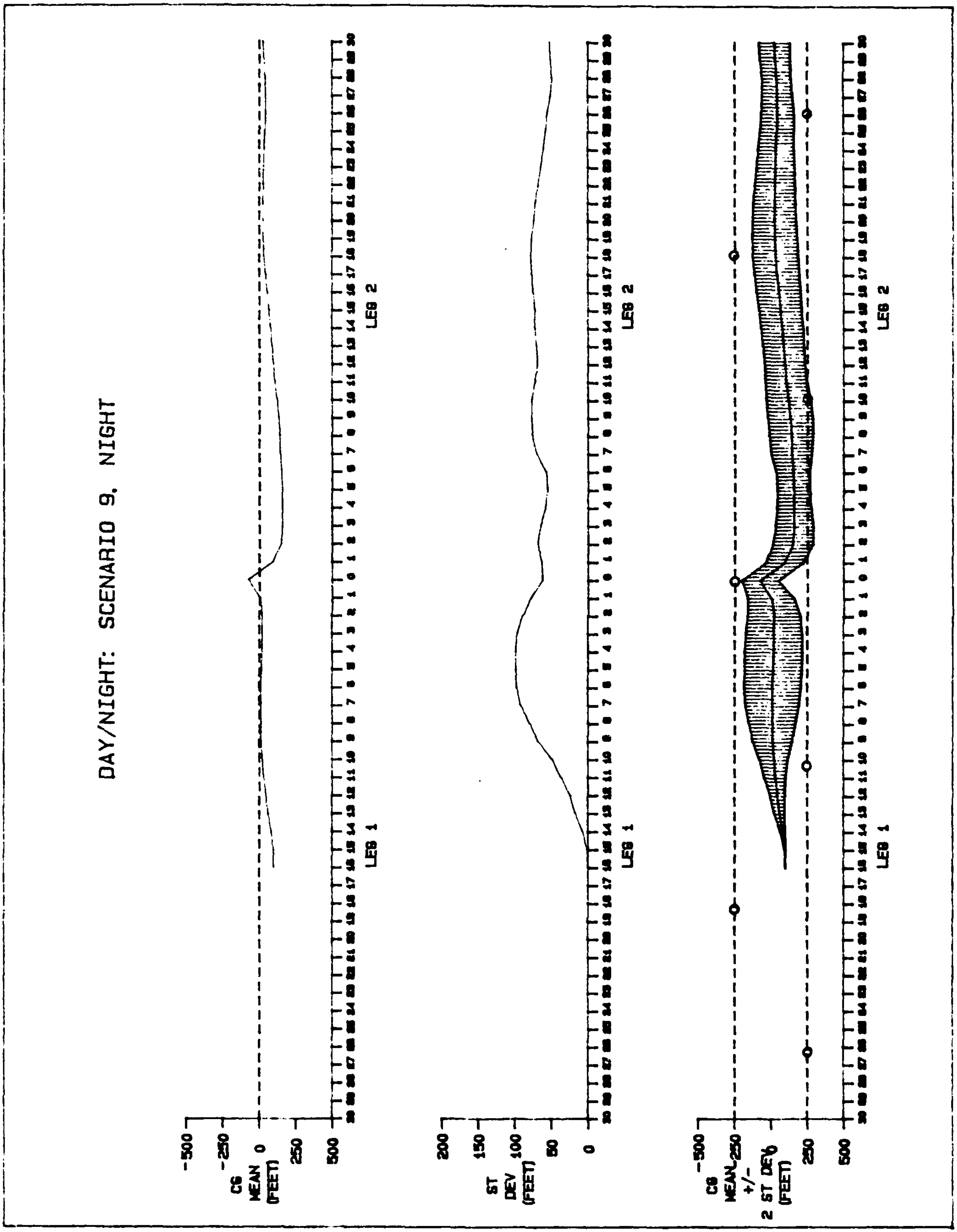
RELATIVE BEARING: SCENARIO 6, ABEAM PULLOUT




RELATIVE BEARING: SCENARIO 7. ABEAM SETUP
CG MEAN (FEET)
ST DEV (FEET)
CG MEAN +/- 2 ST DEV (FEET)
LEG 1
LEG 2

DISTANCE: SCENARIO 8, 2.5 NM




DAY/NIGHT: SCENARIO 9, NIGHT
CG MEAN (FEET)
-500
-250
0
250
500
ST DEV (FEET)
200
150
100
50
0
CG MEAN +/- 2 ST DEV (FEET)
LEG 1
LEG 2

[BLANK]

APPENDIX E

COMPARISON PLOTS SUPPORTING SECTIONS 5, 6, AND 7

The plots which follow are a graphic representation of the comparisons on which the discussions in Sections 5, 6, and 7 were based. They are arranged according to the outlines of the sections. Table E-1 lists the subsections of Sections 5, 6, and 7 and the Appendix D page number on which the relevant plots appear.

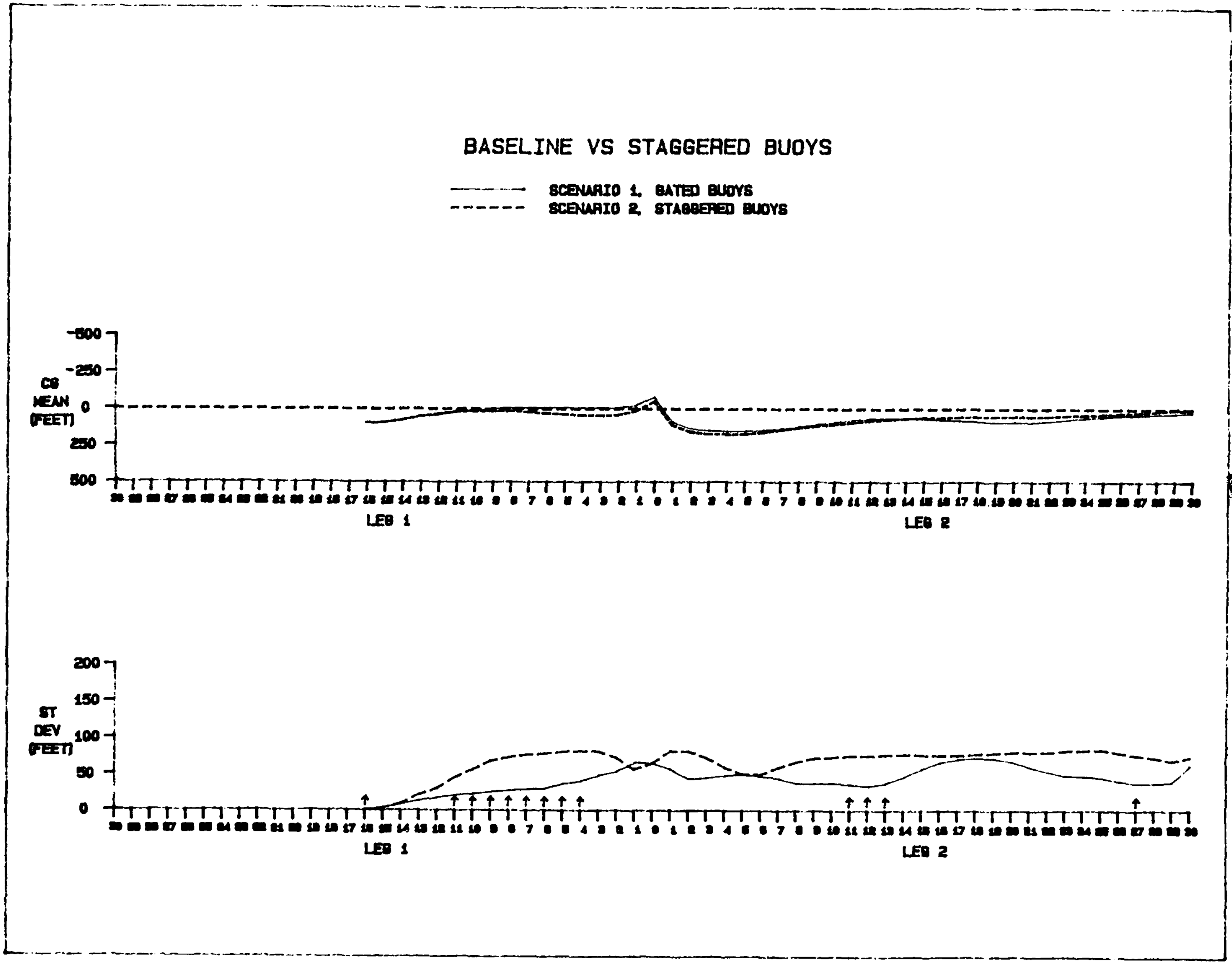
For each subsection there is a "comparison" plot comparing statistics from the two scenarios. This type of plot has been described in Section 4.3.

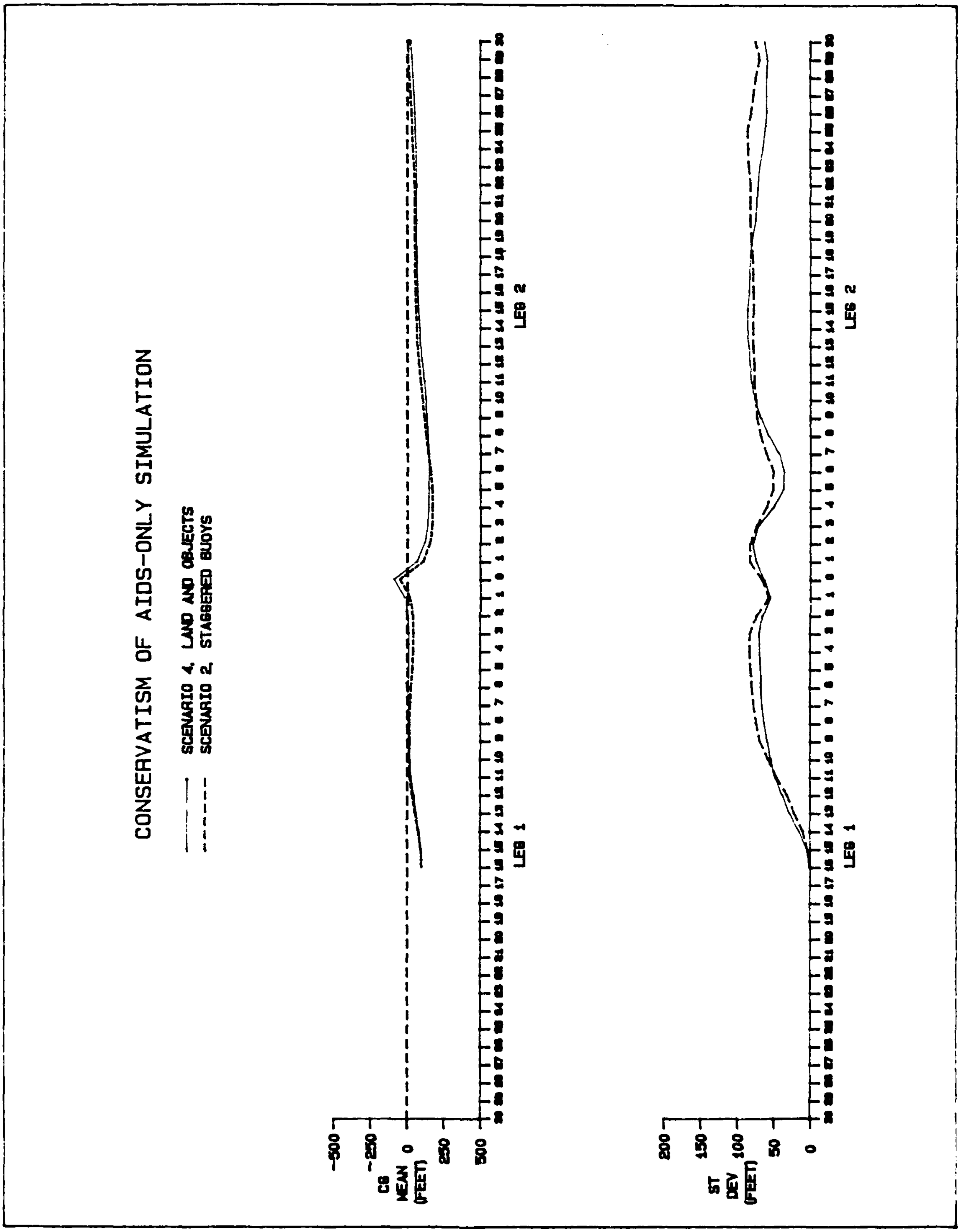
For each comparison there are two sets of axes, one showing the mean and one showing the crosstrack standard deviation as the performance measures. Data is plotted as a continuous unbroken line and a dotted line to distinguish the experimental conditions from each other.

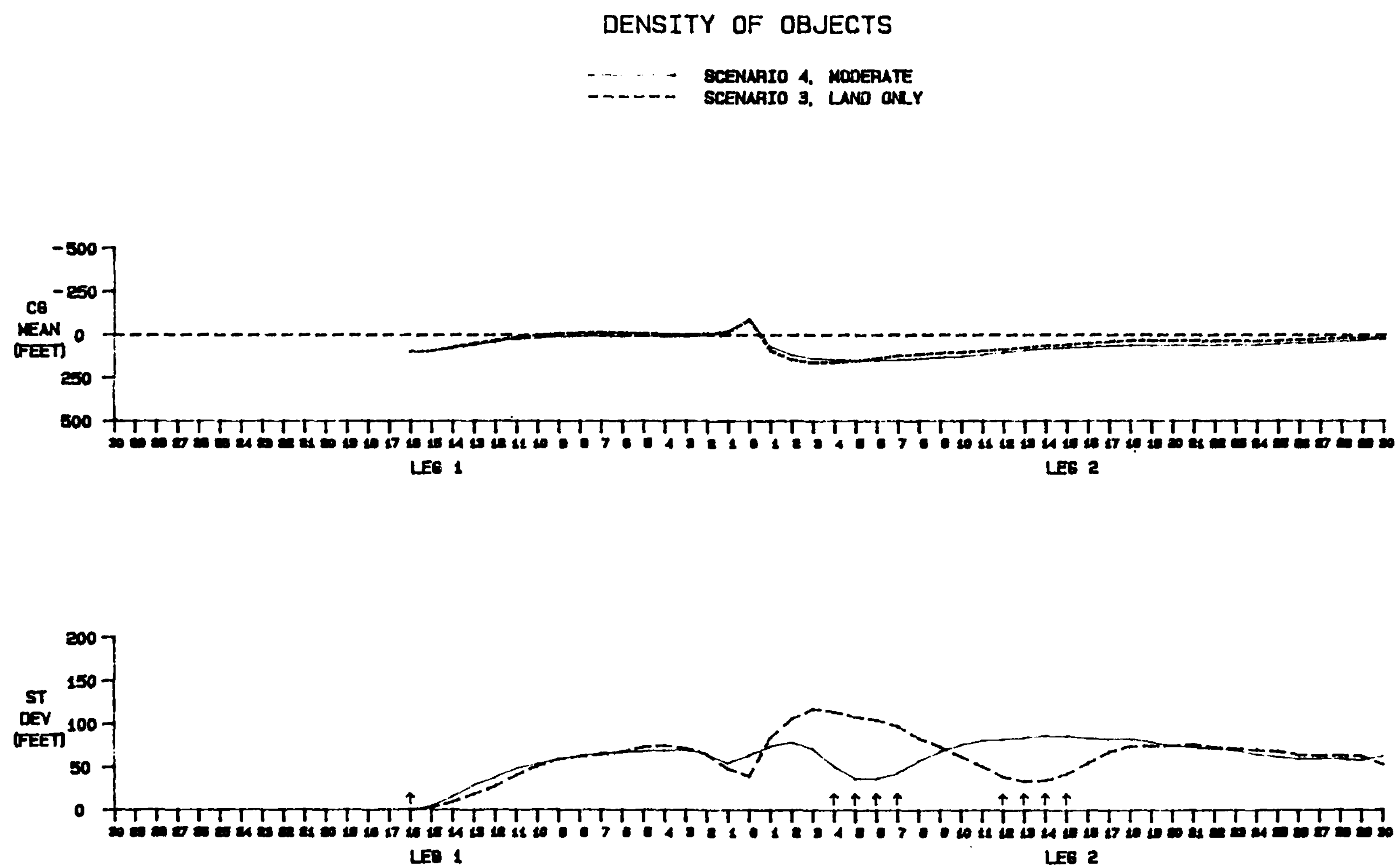
Statistical tests were used to test differences in performance at each data line, to determine if any differences between the conditions were statistically significant. The means were compared using a t-test. The arrows along the axis of the mean plot indicate a different at the 0.10 level of significance. The standard deviations were compared as variances using an F test. The arrows along the axis of the standard deviation plot also indicate a difference at the 0.10 level of significance.

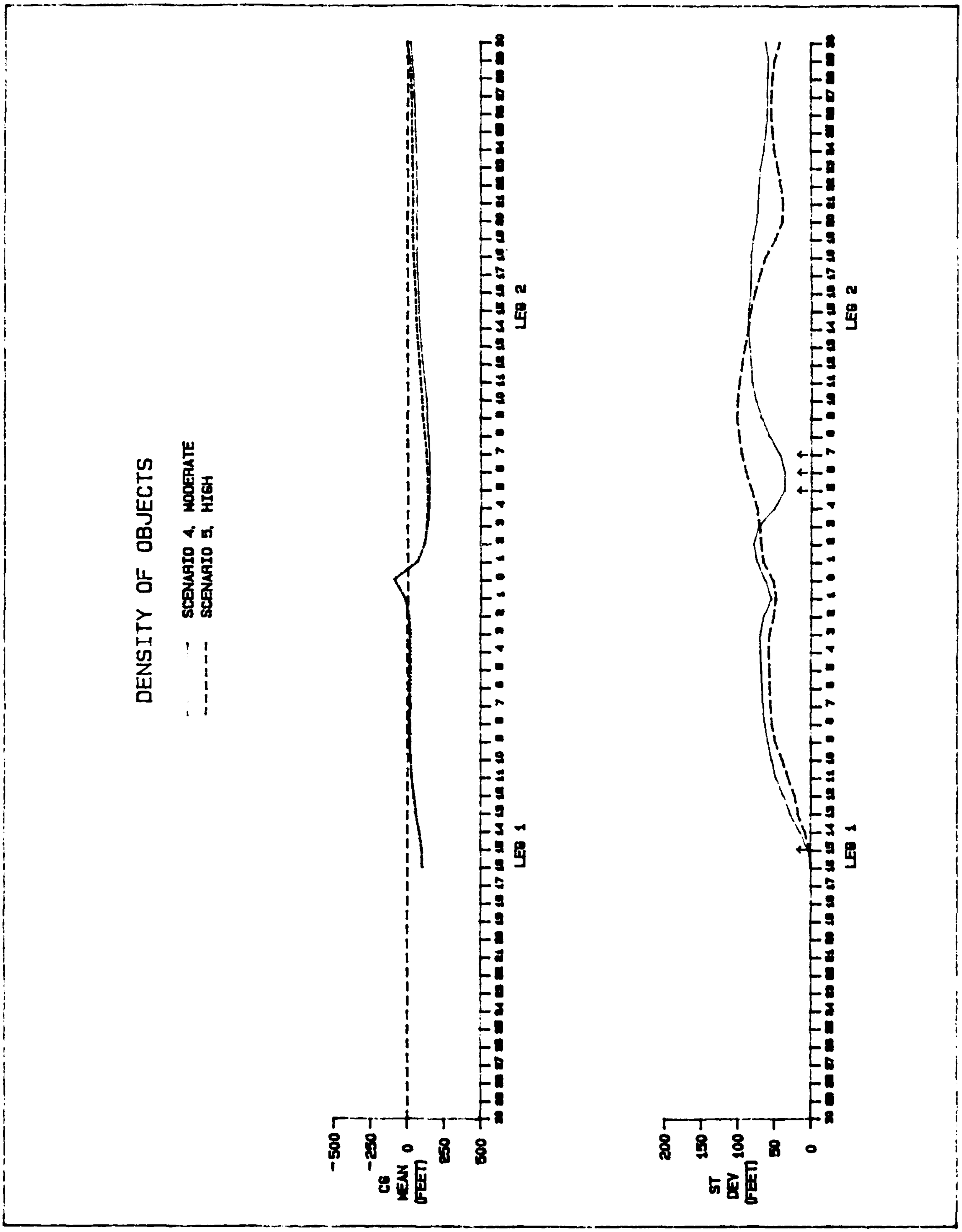
TABLE E-1. COMPARISONS BETWEEN EXPERIMENT SCENARIOS

Objective	Scenarios	Text Section	Page
Aid Arrangements	1 vs 2	5.2.1	E-3
Representative Visual Environment	2 vs 4	5.2.2	E-4
Density of Objects	4 vs 3, 4 vs 5	5.3.1	E-5, E-6
Relative Bearing of Objects	4 vs 6, 4 vs 7	5.3.2	E-7, E-8
Distance	4 vs 8	5.3.3	E-9
Day/Night	4 vs 9	5.3.4	E-10
Preferred Arrangement	1 vs 2 ... 9	5.4	E-3 E-11 thru E-17
Aids-Only Conservatism	4 vs 2	6.2	E-4

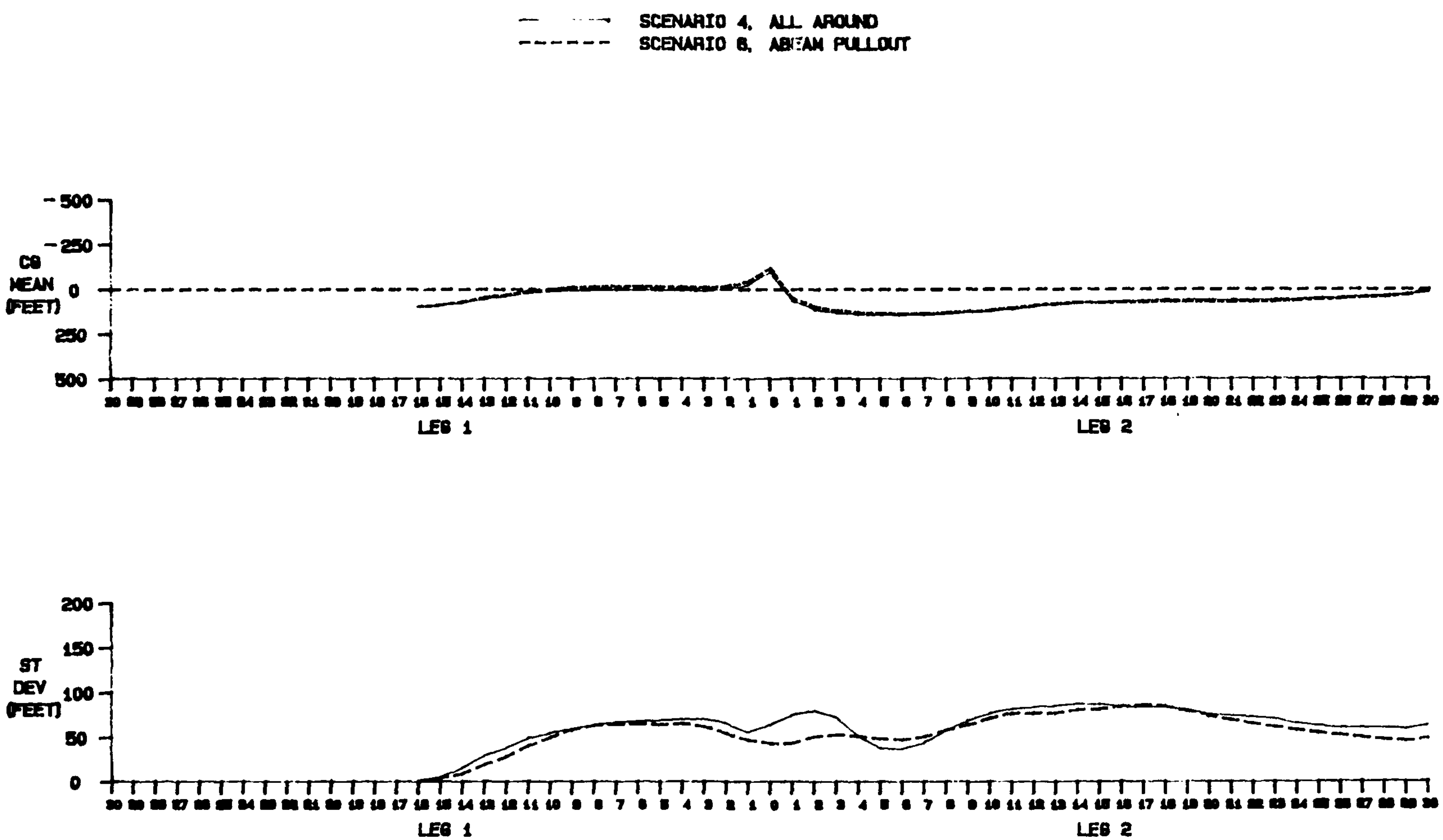

BASELINE VS STAGGERED BUOYS
SCENARIO 1, GATED BUOYS
SCENARIO 2, STAGGERED BUOYS
CG MEAN (FEET)
-500
-250
0
250
500
LEG 1
LEG 2
ST DEV (FEET)
200
150
100
50
0
LEG 1
LEG 2

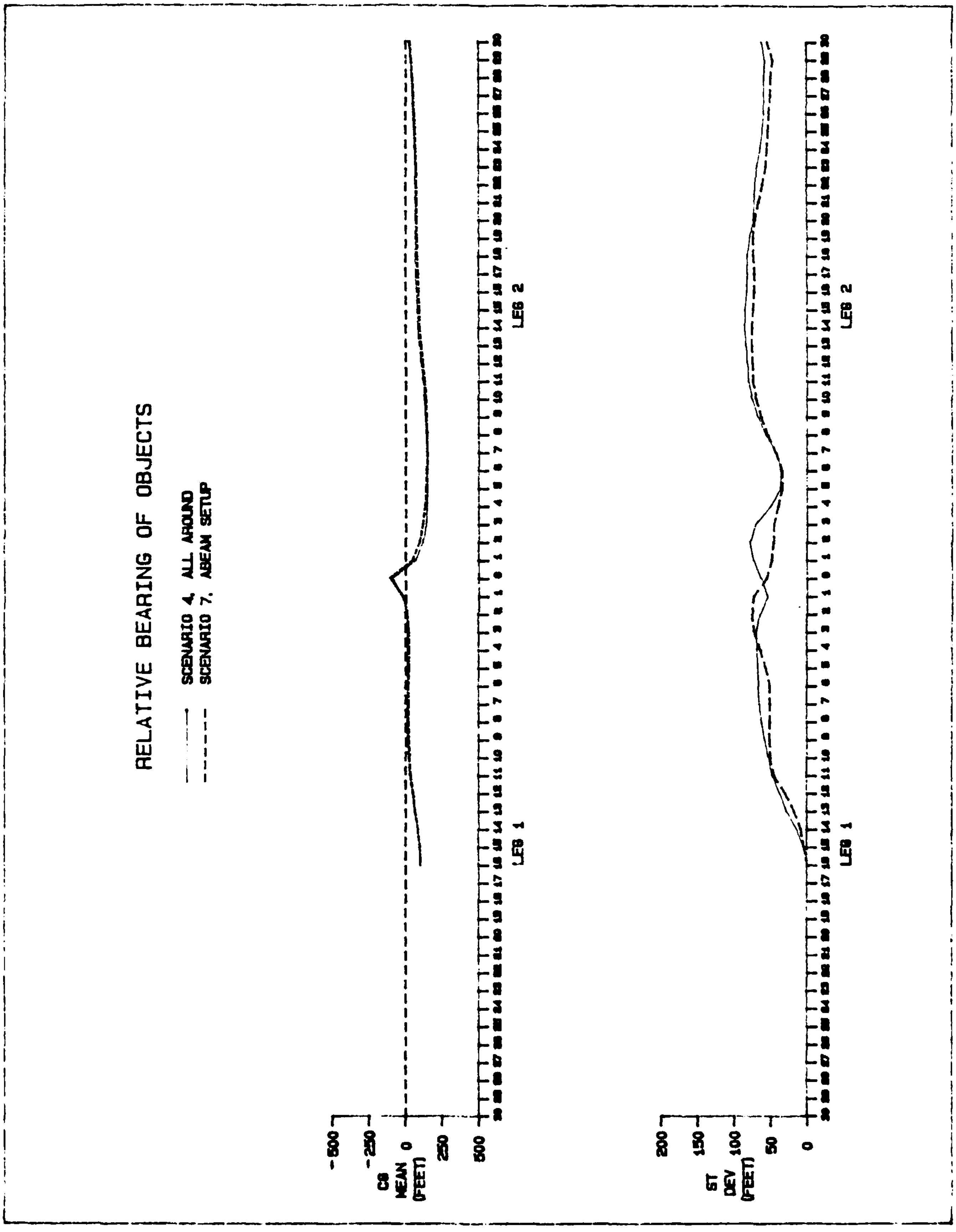

CONSERVATISM OF AIDS-ONLY SIMULATION
SCENARIO 4, LAND AND OBJECTS
SCENARIO 2, STAGGERED BUOYS
CG MEAN (FEET)
-500
-250
0
250
500
LEG 1
LEG 2
ST DEV (FEET)
200
150
100
50
0
LEG 1
LEG 2

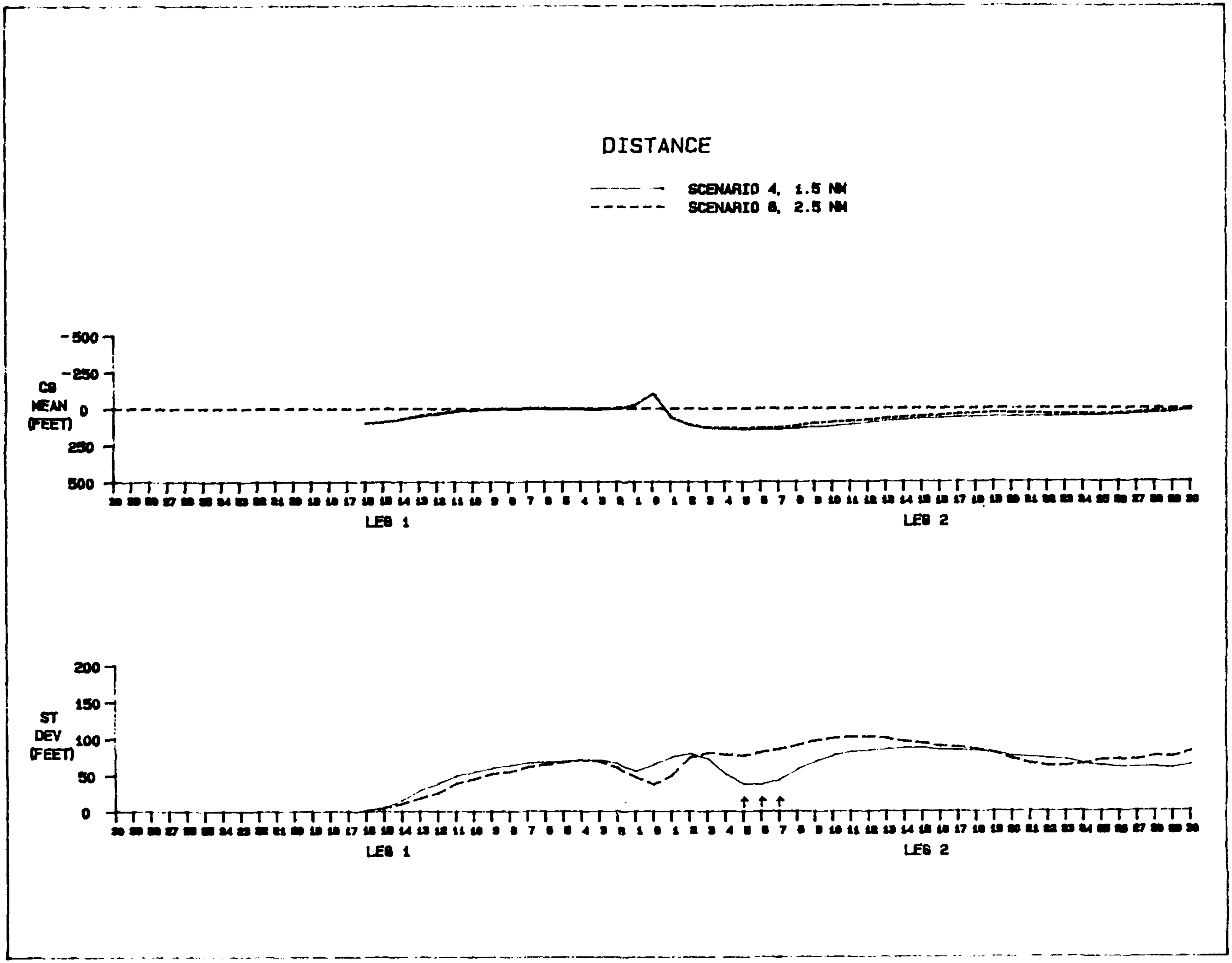

DENSITY OF OBJECTS
SCENARIO 4, MODERATE
SCENARIO 3, LAND ONLY
CG MEAN (FEET)
-500
-250
0
250
500
LEG 1
LEG 2
ST DEV (FEET)
200
150
100
50
0
LEG 1
LEG 2

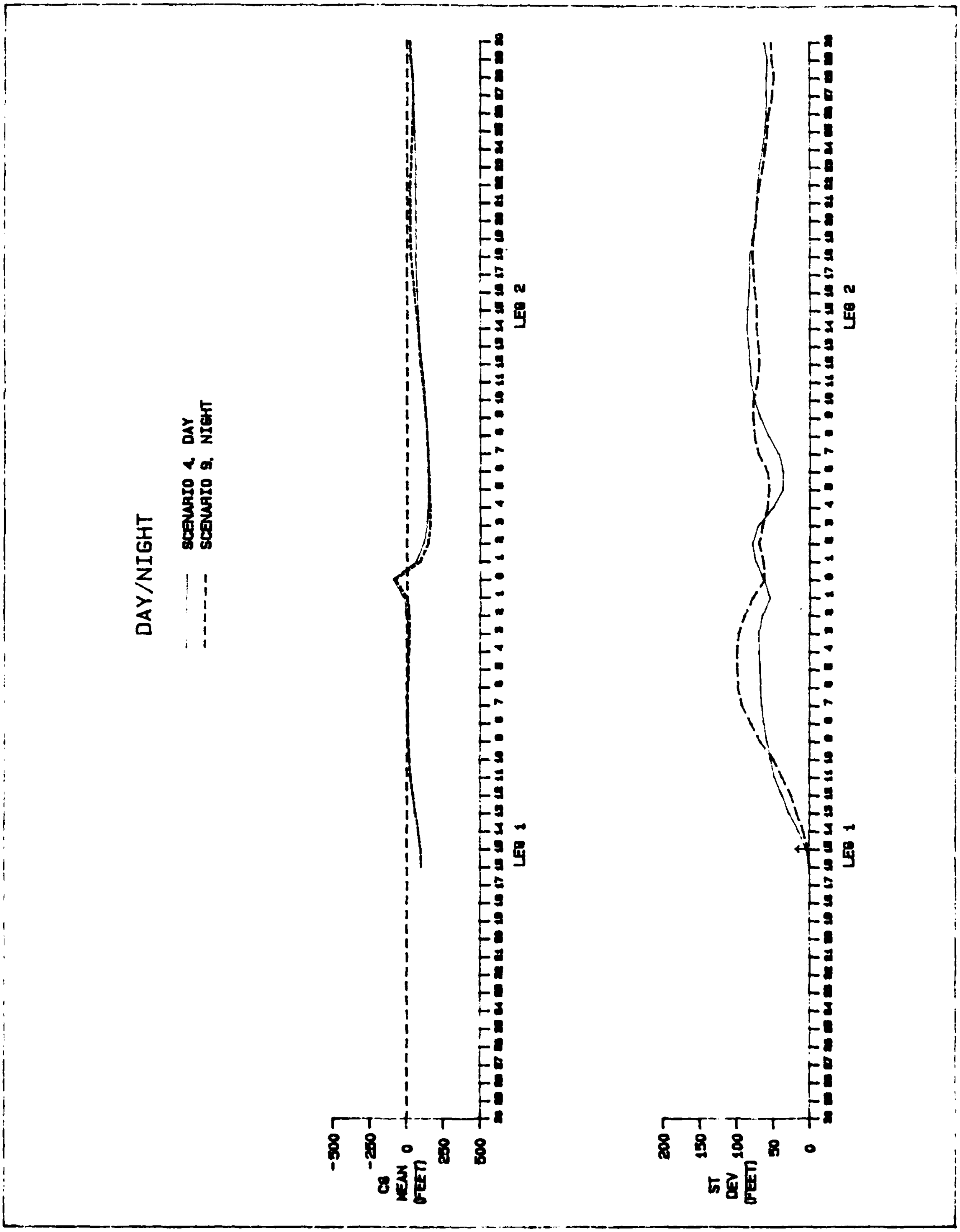

DENSITY OF OBJECTS
SCENARIO 4, MODERATE
SCENARIO 5, HIGH
CG MEAN (FEET)
-500
-250
0
250
500
ST DEV (FEET)
200
150
100
50
0
LEG 1
LEG 2

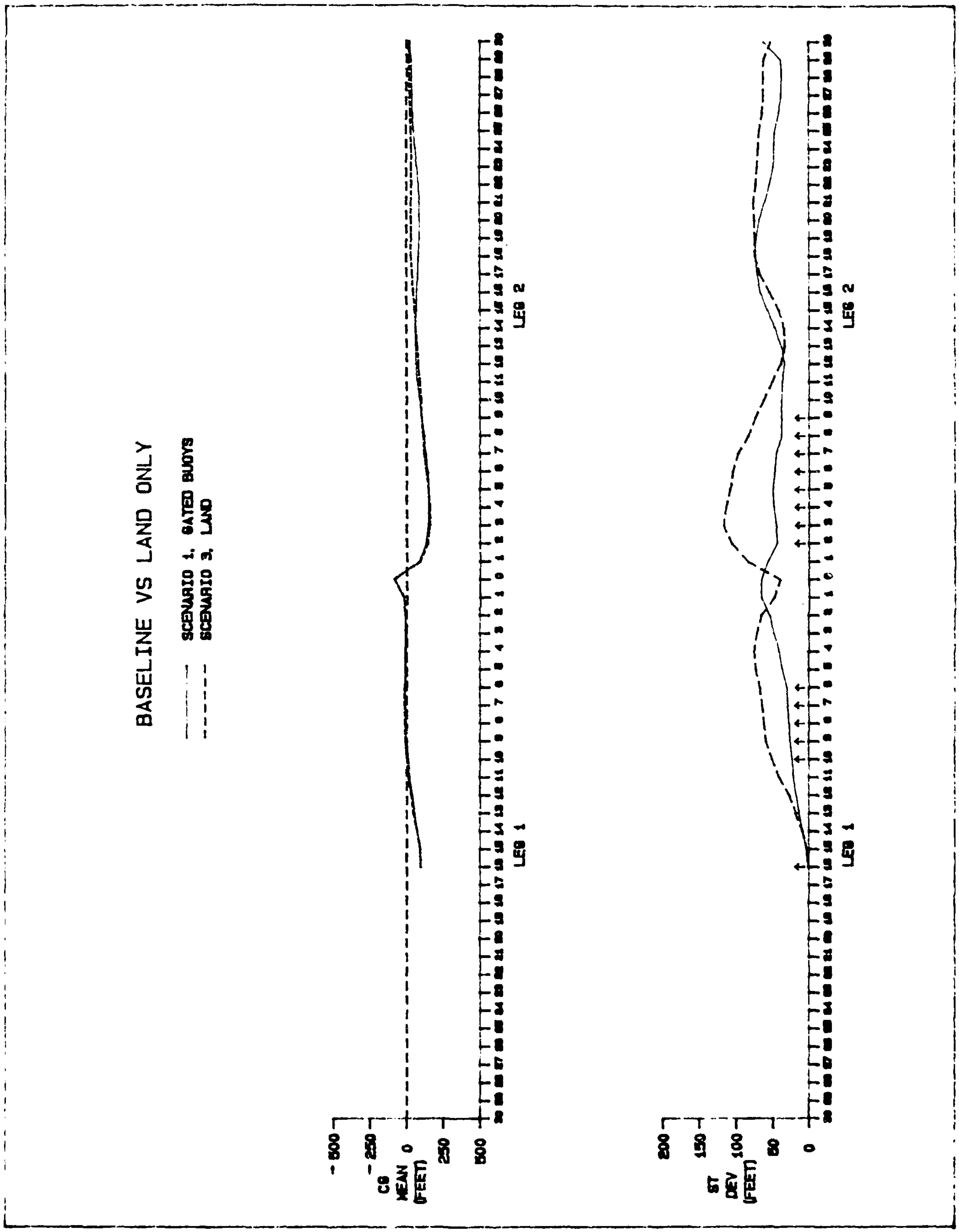
RELATIVE BEARING OF OBJECTS

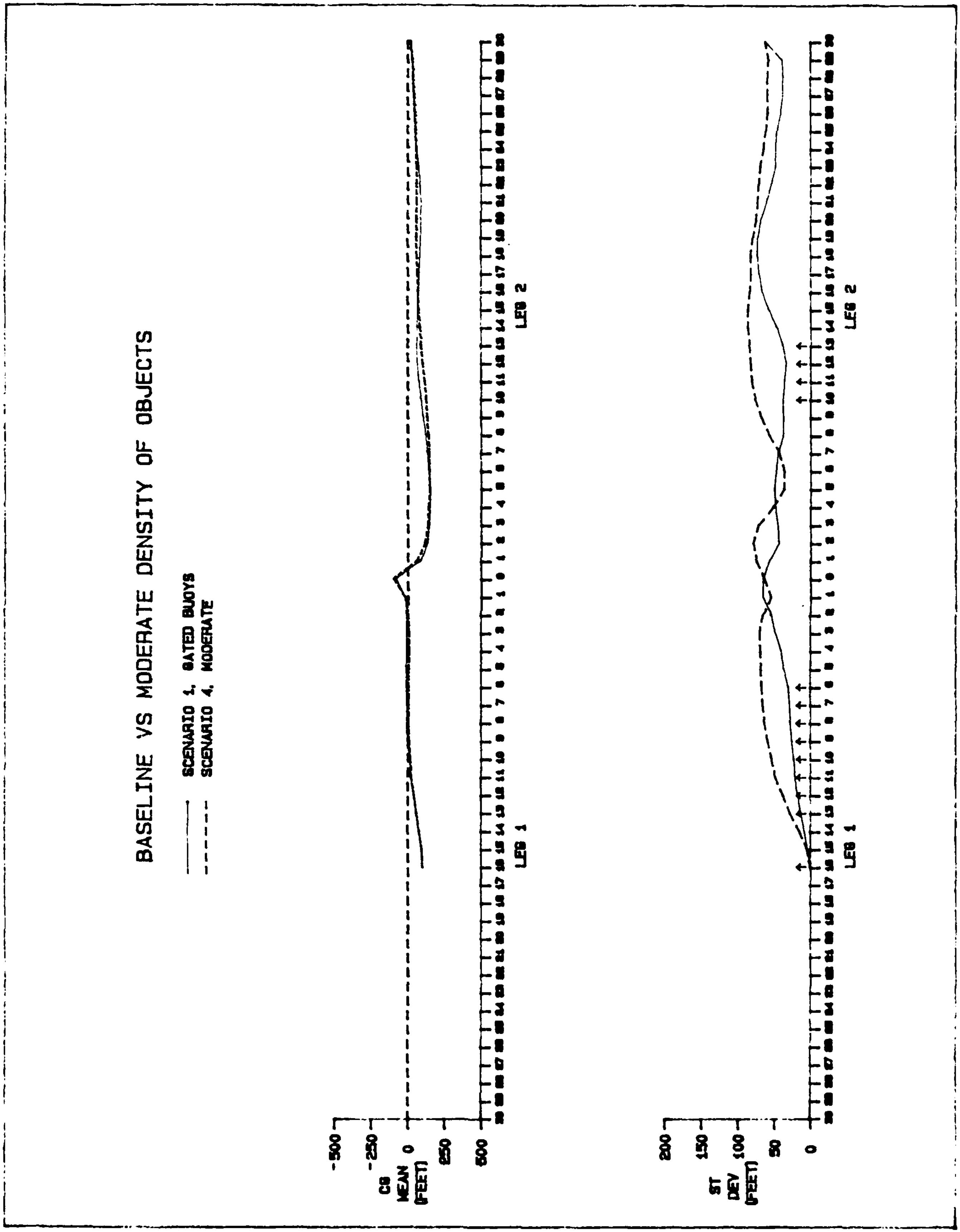



RELATIVE BEARING OF OBJECTS
SCENARIO 4, ALL AROUND
SCENARIO 7, ABEAM SETUP
CG MEAN (FEET)
-500
-250
0
250
500
ST DEV (FEET)
200
150
100
50
0
LEG 1
LEG 2

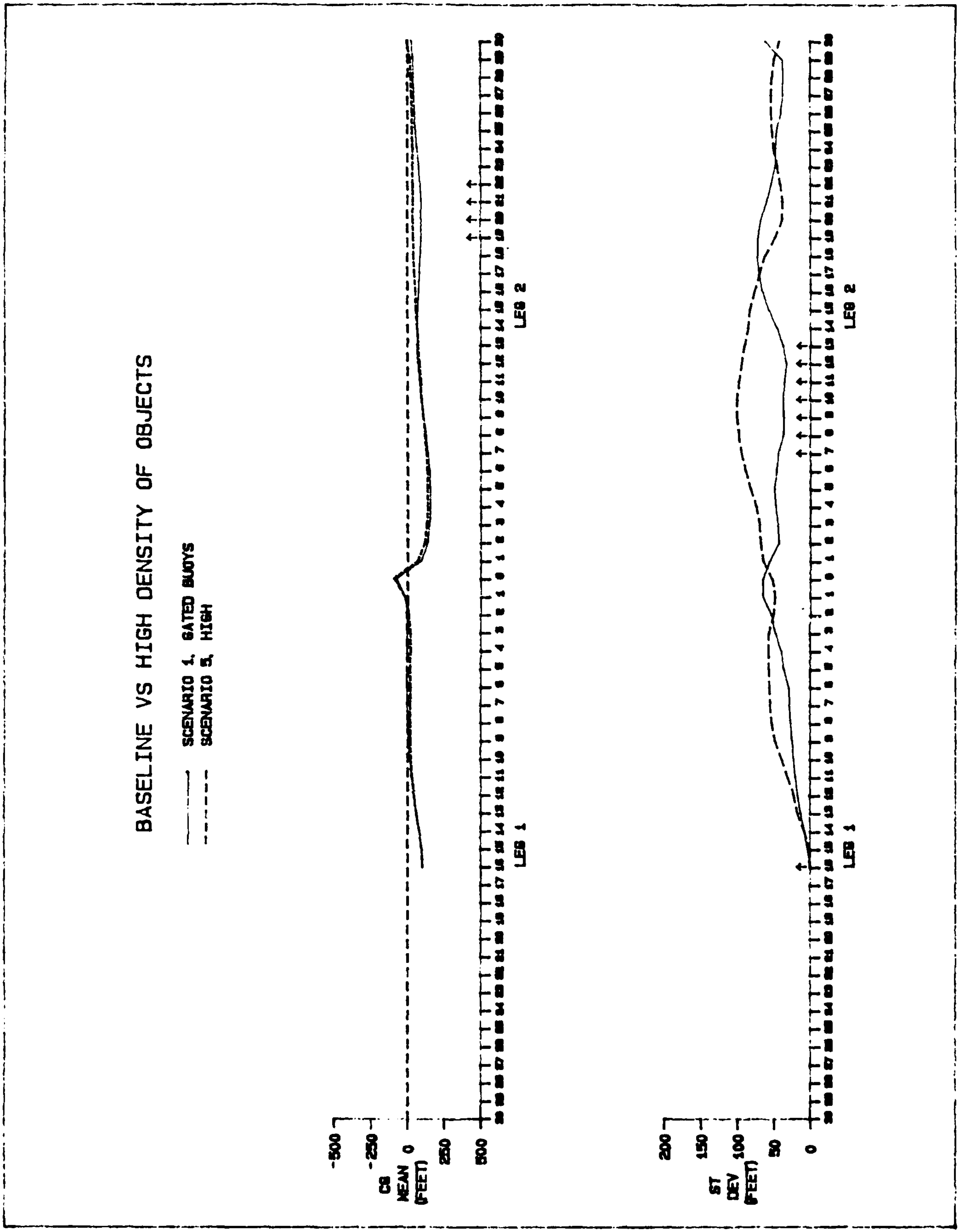

DISTANCE
SCENARIO 4, 1.5 NM
SCENARIO 8, 2.5 NM
CG MEAN (FEET)
-500
-250
0
250
500
LEG 1
LEG 2
ST DEV (FEET)
200
150
100
50
0
LEG 1
LEG 2


DAY/NIGHT
SCENARIO 4, DAY
SCENARIO 9, NIGHT
CS MEAN (FEET)
-500
-250
0
250
500
LEG 1
LEG 2
ST DEV (FEET)
200
150
100
50
0

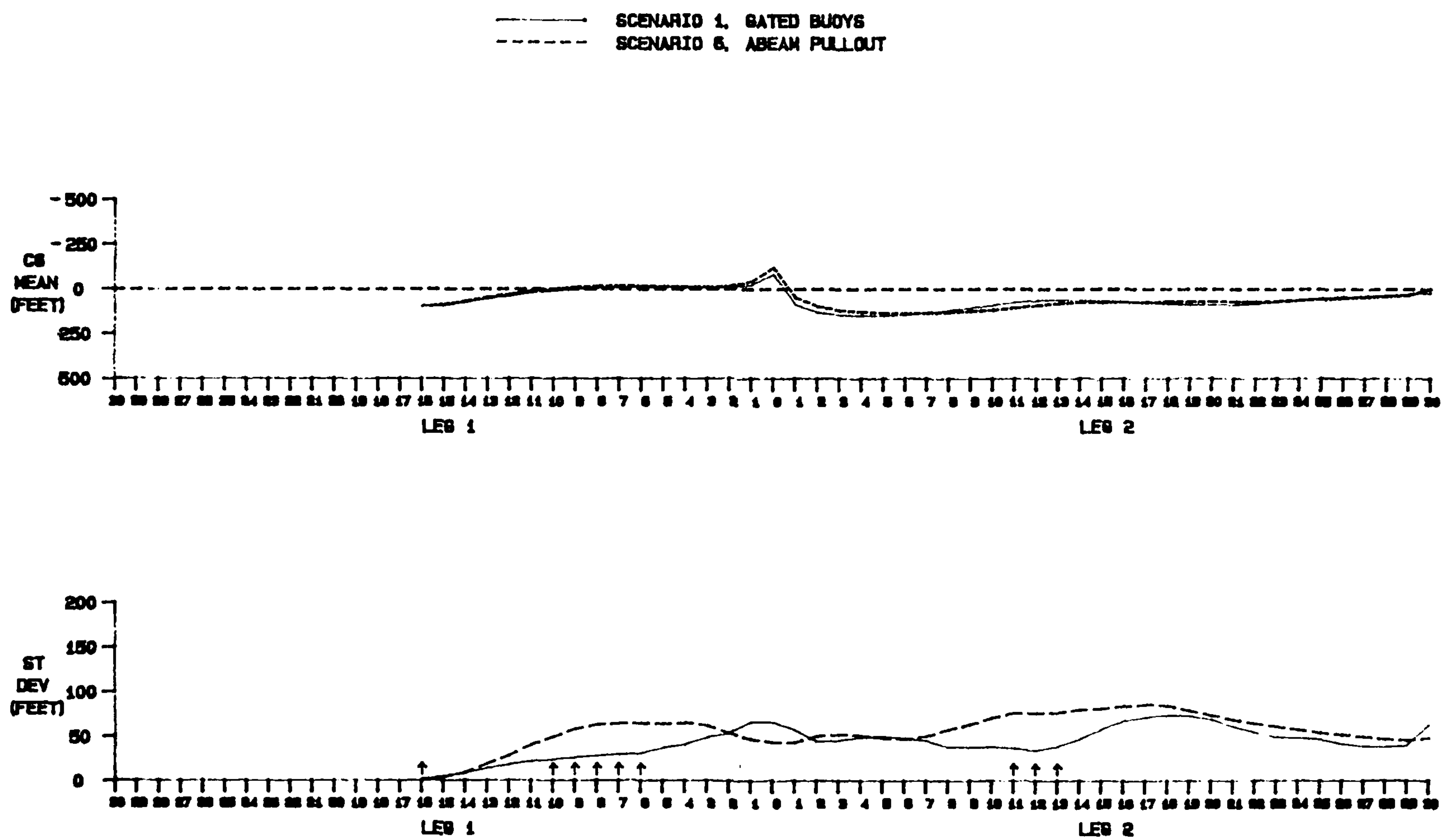

BASELINE VS LAND ONLY
SCENARIO 1, GATED BUOYS
SCENARIO 3, LAND
CG MEAN (FEET)
-500
-250
0
250
500
ST DEV (FEET)
200
150
100
50
0
LEG 1
LEG 2



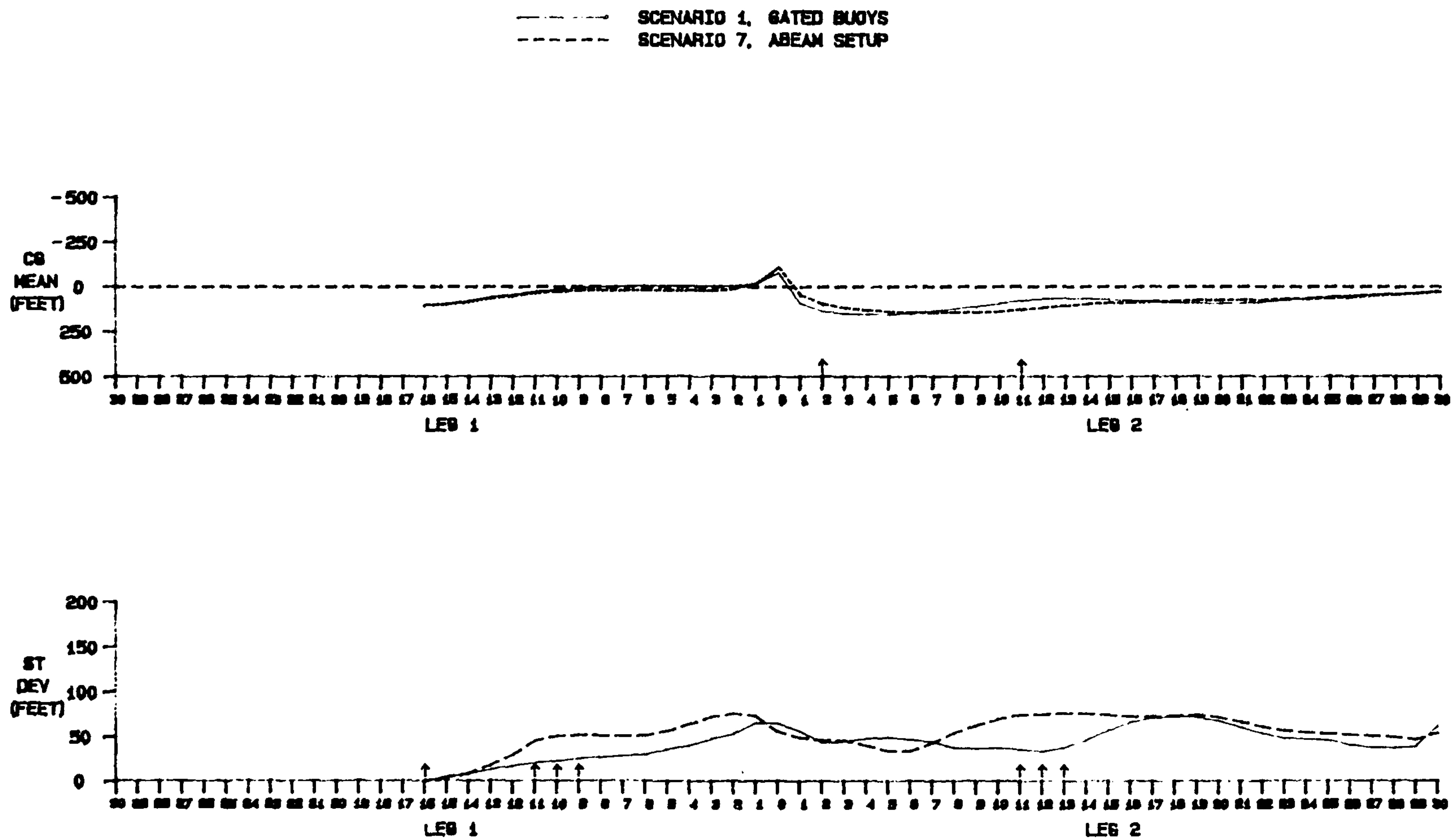
BASELINE VS MODERATE DENSITY OF OBJECTS
SCENARIO 1, GATED BUOYS
SCENARIO 4, MODERATE
CB MEAN (FEET)
-500
-250
0
250
500
ST DEV (FEET)
200
150
100
50
0
LEG 1
LEG 2

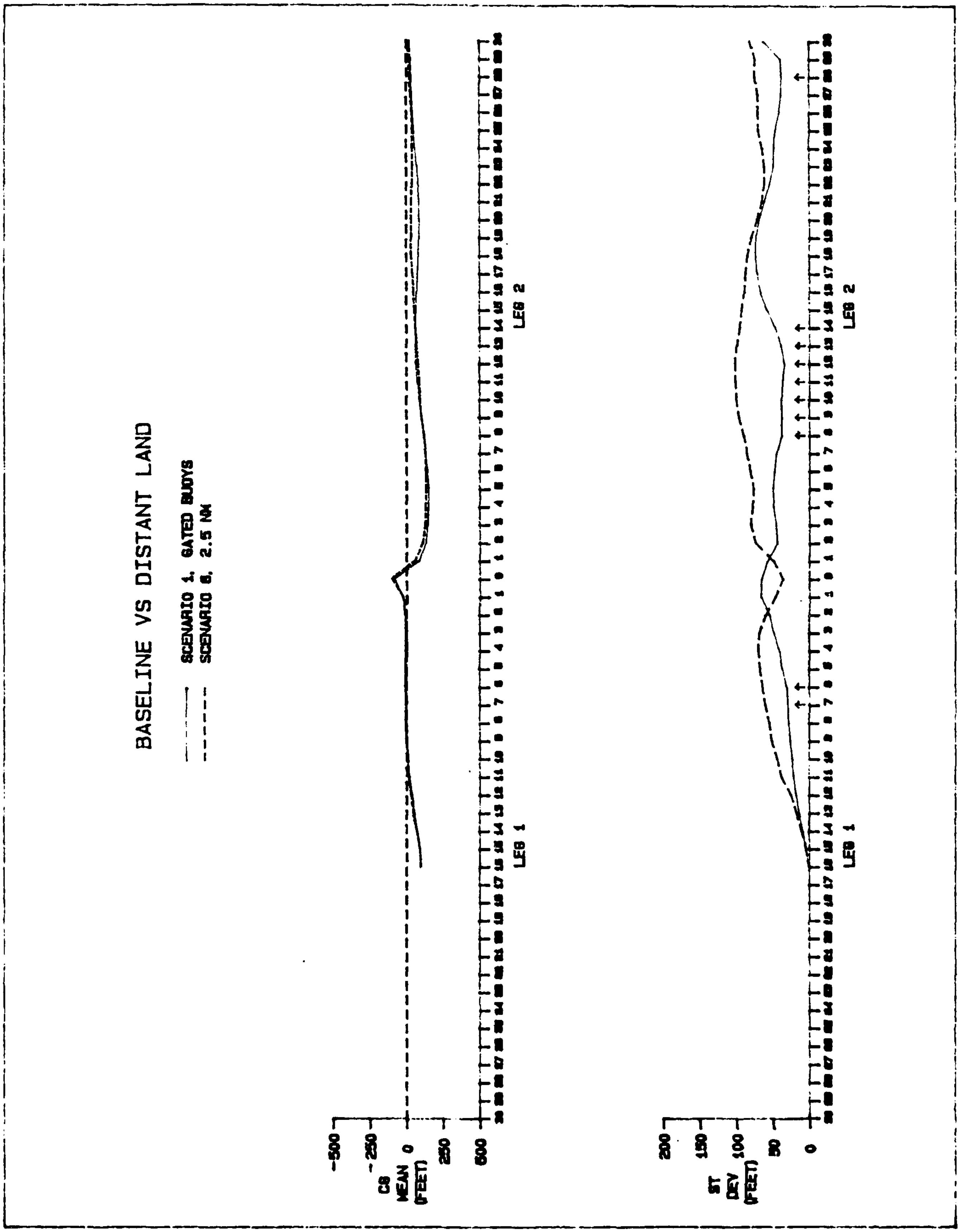

BASELINE VS HIGH DENSITY OF OBJECTS
SCENARIO 1, GATED BUOYS
SCENARIO 5, HIGH
CS MEAN (FEET)
-500
-250
0
250
500
ST DEV (FEET)
200
150
100
50
0
LEG 1
LEG 2

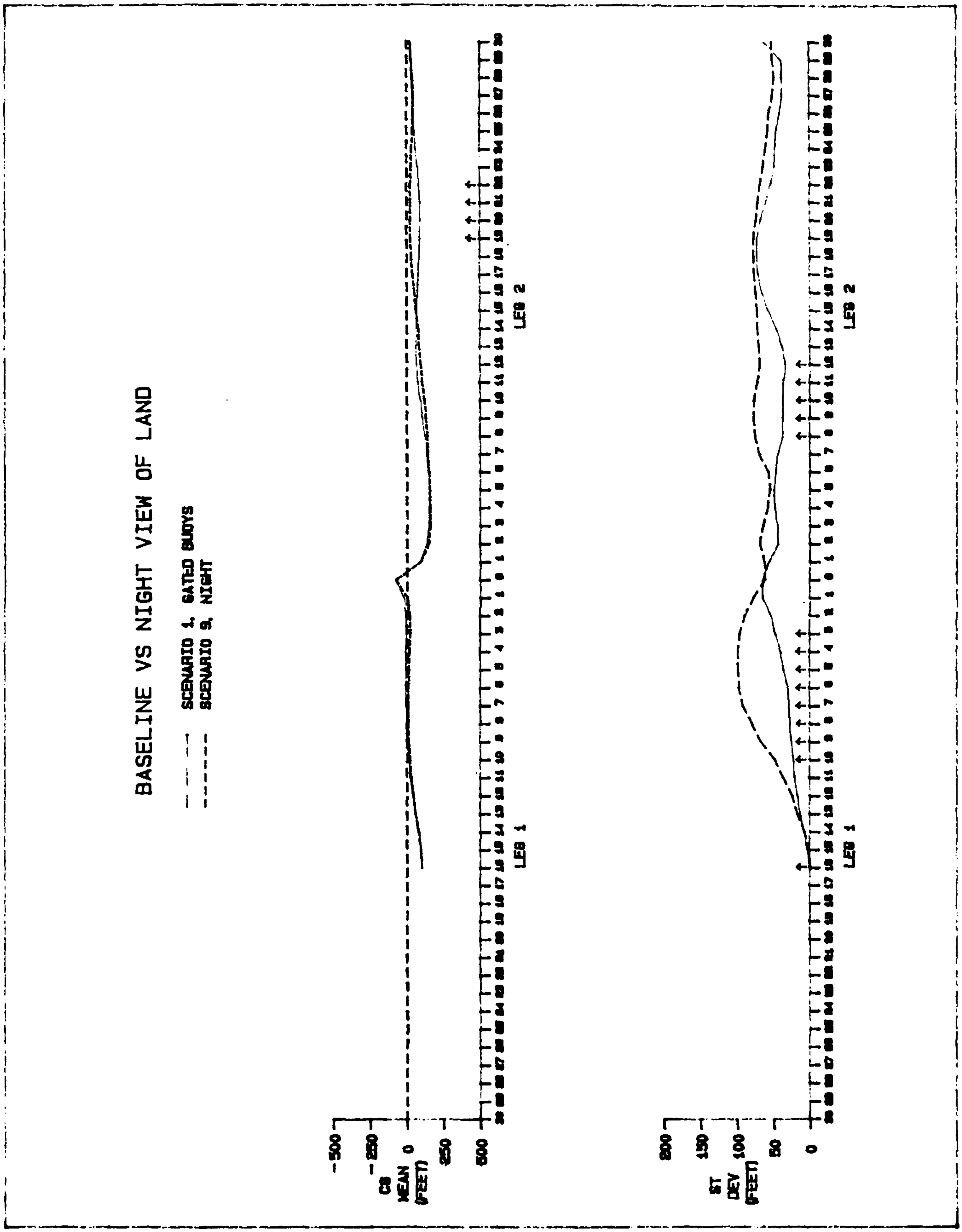
BASELINE VS LAND ABEAM PULLOUT



BASELINE VS LAND ABEAM SETUP




BASELINE VS DISTANT LAND
SCENARIO 1, GATED BUOYS
SCENARIO 6, 2.5 NM
CS MEAN (FEET)
-500
-250
0
250
500
ST DEV (FEET)
200
150
100
50
0
LEG 1
LEG 2


BASELINE VS NIGHT VIEW OF LAND
SCENARIO 1, GATED BUOYS
SCENARIO 9, NIGHT
CB MEAN (FEET)
-500 -250 0 250 500
ST DEV (FEET)
200 150 100 50 0
LEG 1
LEG 2

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Smith, M.W., K.L. Marino, J. Multer, and J.D. Moynehan Aids to Navigation Principal Findings Report: Validation for a Simulator-Based Design Project CG-D-06-84, United States Coast Guard, Washington, D.C. 20593, July 1984 (NTIS AD-A146789).

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